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WHERE THE RIVER MEETS THE SEA:

Geology and landforms of the lower Coppermine River valley and Kugluktuk, Nunavut

L.A. Dredge

2001

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Cover illustration

Hamlet of Kugluktuk in AD 2000, showing the townsite, Coppermine River, and delta shoals in the foreground. View to the south. GSC 2000-012A

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WHERE THE RIVER MEETS THE SEA:

Geology and landforms of the lower Coppermine River valley and Kugluktuk, Nunavut

Abstract

This resource book describes the geography and geology of areas of Coronation Gulf accessible from Kugluktuk. Part I presents an introduction to the land and the people. With the aid of geology maps, part II describes how the land evolved over the last four billion years, especially the role played by continental ice sheets and postglacial events. Part III provides an overview of processes shaping the landscape at present, and emphasizes permafrost features that typify the Arctic environment. Part IV is a guidebook to sites of geological interest. It highlights a walk around the hamlet, points of interest in the Coppermine River valley between Kugluktuk and Bloody Fall, and the principal features along the coast as far as the west end of Coronation Gulf.

Résumé

Cet ouvrage de référence décrit la géographie et la géologie de certains secteurs du golfe du Couronnement accessibles depuis Kugluktuk. La première partie consiste en une introduction à la région et à ses habitants. La deuxième partie explique à l'aide de cartes géologiques comment les terres ont évolué au cours des quatre derniers milliards d'années, en soulignant particulièrement le rôle des nappes glaciaires continentales et des événements postglaciaires. La troisième partie donne un aperçu des processus qui modifient actuellement le paysage, en mettant l'accent sur les formes du pergélisol caractéristiques du milieu arctique. Quant à la quatrième partie, il s'agit d'un guide des sites d'intérêt géologique de la région. Il regroupe de l'information sur une randonnée pédestre autour du hameau; une liste des points d'intérêt dans la vallée de la rivière Coppermine, entre Kugluktuk et les chutes Bloody; et une liste des principales entités le long de la côte, jusqu'à l'extrémité ouest du golfe du Couronnement.

PART I: INTRODUCTION TO KUGLUKTUK

Kugluktuk (formerly known as Coppermine) is a small settlement situated on the coast of the Arctic mainland above the Arctic Circle (Lat. 67°49'N, Long. 115°06'W; Fig. 1, cover photo). Its population in the year 2000 is 1250. The hamlet lies on a rocky hill that slopes gently northward to the shore of Coronation Gulf, part of the Arctic Ocean. Eastern and southern views overlook the delta and lower reaches of the Coppermine River. Its geographic situation provides a wide range of habitats for wildlife and plants, and a variety of coastal, terrestrial, and fluvial landforms. Its climatic environment also makes it an accessible natural laboratory for the examination of frozen-ground processes.

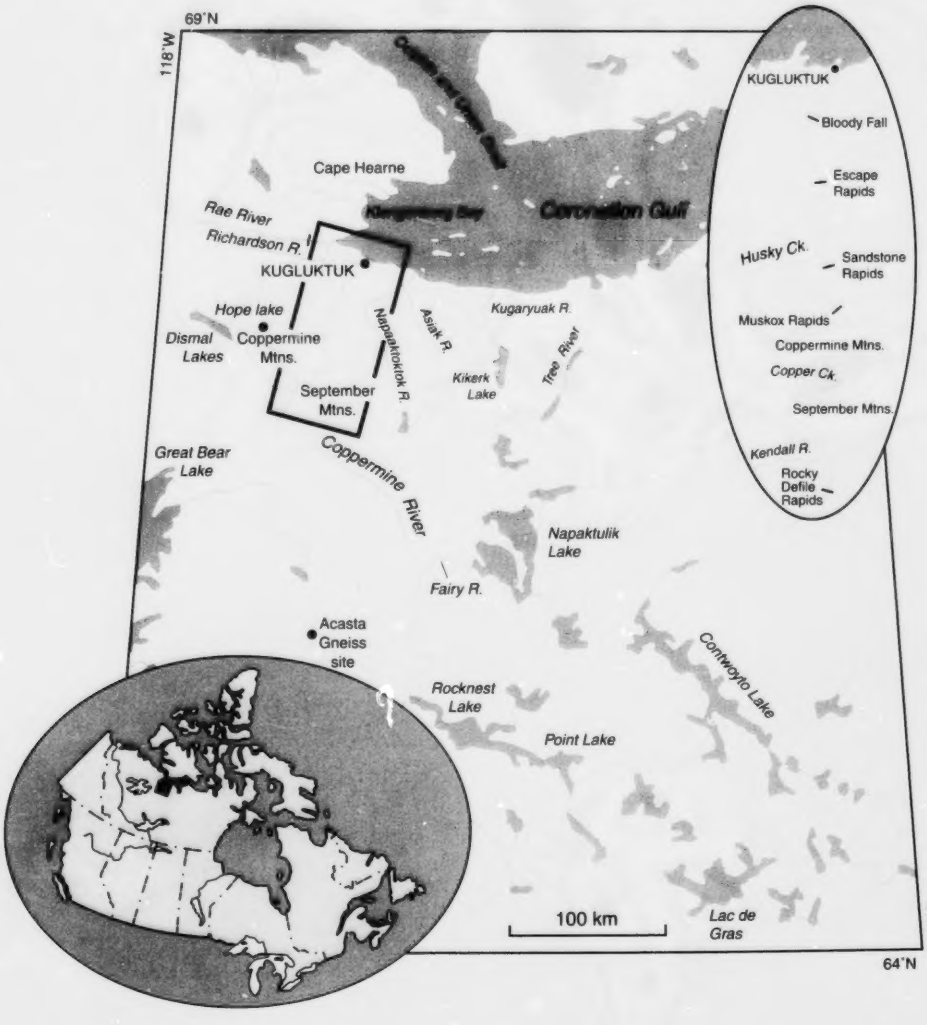
69°N
118°W
Cape Hearne
Coronation Gulf
Rae River
Richardson R.
KUGLUKTUK
Hope lake
Dismal Lakes
Coppermine Mtns.
September Mtns.
Napaaktoktok R.
Asiak R.
Kugaryuak R.
Kikerk Lake
Tree River
Great Bear Lake
Coppermine River
Napaktulik Lake
Fairy R.
Acasta Gneiss site
Contwoyto Lake
Rocknest Lake
Point Lake
100 km
Lac de Gras
108°W
64°N
KUGLUKTUK
Bloody Fall
Escape Rapids
Husky Ck.
Sandstone Rapids
Muskox Rapids
Coppermine Mtns.
Copper Ck.
September Mtns.
Kendall R.
Rocky Defile Rapids

Figure 1. Location map and place names used in the report.

This handbook outlines the events that have shaped the landscape of the lower Coppermine River region, and the people who live there. Parts I and II describe how the land and its people came to be. Part III describes permafrost conditions and the main processes affecting the present-day landscape. Part IV includes several geotours of Kugluktuk and its surroundings.

Setting

Vegetation

The Coppermine area lies within the treeless Southern Arctic Tundra (Fig. 2). This type of terrain is also known as the 'Barren Grounds'. The variety of habitats around Kugluktuk has made it a haven for botanists. Heath–dwarf birch communities, herbaceous plants such as Labrador tea (*Ledum*), avens (*Dryas*), cranberries, heather, and saxifrage, and an array of lupins and other wildflowers (Edlund, 1986) occupy drier soils

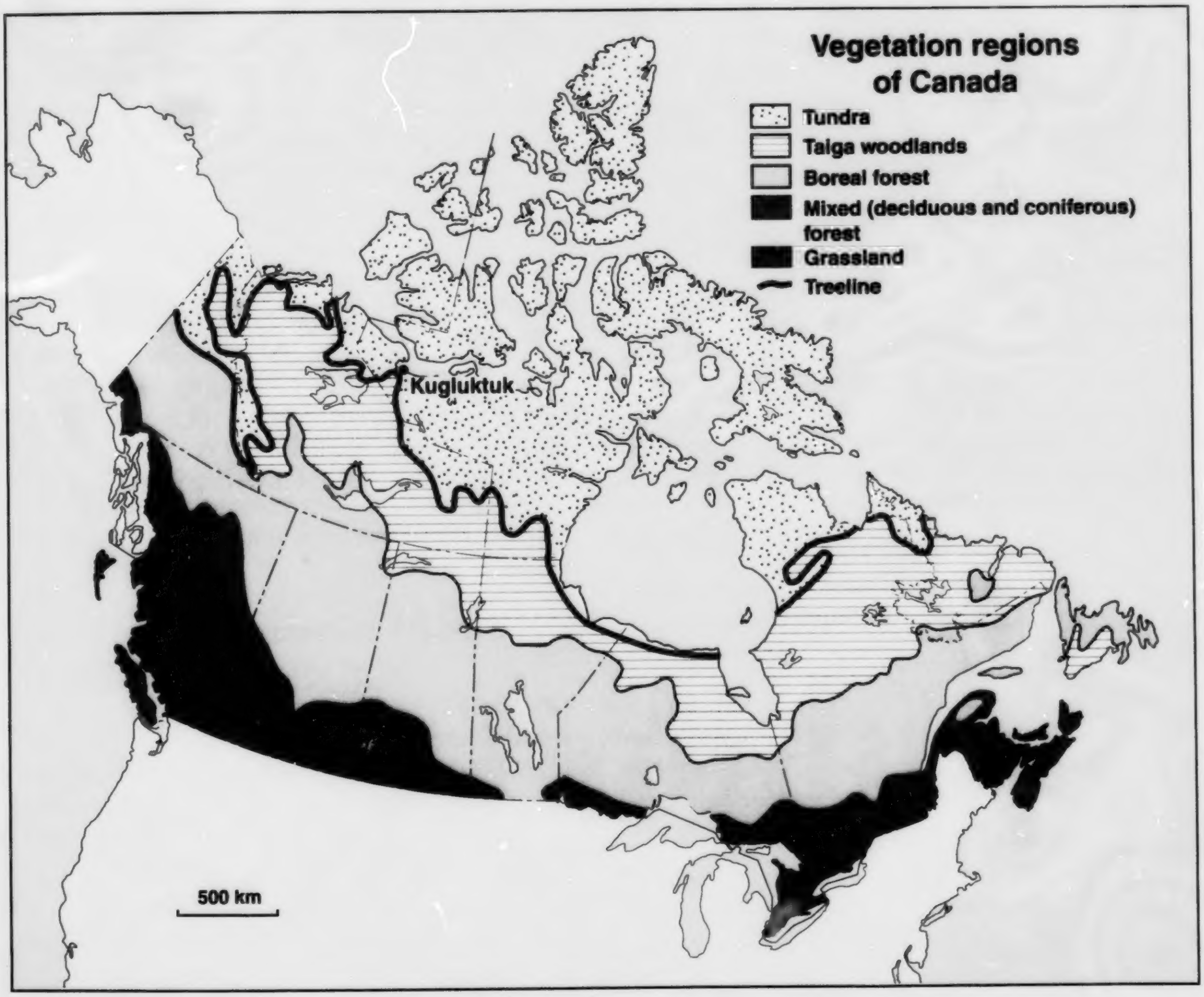
Vegetation regions of Canada
Tundra
Taiga woodlands
Boreal forest
Mixed (deciduous and coniferous) forest
Grassland
Treeline
Kugluktuk
500 km

Figure 2. Vegetation regions of Canada, and the present position of the treeline.

on uplands and raised-beach ridges. More luxuriant willow–dwarf birch communities colonize protected slopes along creeks. Willows up to 3 m tall grow along the slopes of sheltered gullies. Cotton grass, sedge, and moss are widespread on wet terrain. Hardy beach grasses and vetch have colonized the shore. Rock surfaces are generally either bare or lichen covered.

The Kugluktuk area lies north of the treeline. On upland terrain, the open taiga woodland ecozone begins about 150 km south of the river mouth, but a corridor of open woodland juts northward from the forest edge, within the Coppermine River valley, as far north as Escape Rapids (Fig. 3). This woodland may mark the most northerly position of the regional treeline following the last ice age. Later migration of the treeline southward on the uplands several thousand years ago has been variously attributed to forest fires, infestations of beetles, and climate change. The latter is the most likely.

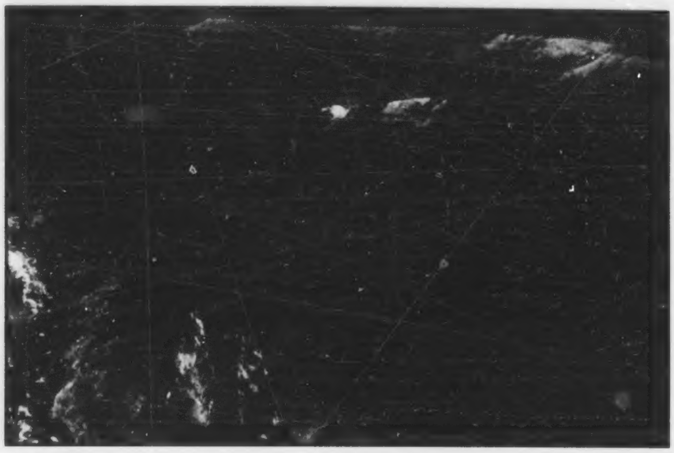

Figure 3. *Stunted spruce trees near Escape Rapids mark the most northerly extension of the treeline in the Coppermine area. Adjacent uplands are treeless. Photograph by L.A. Dredge. GSC 2000-012B*

Climate

Kugluktuk is affected by Arctic air masses year-round, and experiences a maritime Arctic climate characterized by short, cool summers and long, cold winters. Open water in Coronation Gulf in summer can result in periods of rain or low-overcast conditions. The mean annual air temperature is -12°C (Fig 4). Monthly averages range from -31°C in February, the coldest month, to 10°C in July. The coldest recorded temperature is -50°C, and the warmest is 32°C. Kugluktuk receives about 202 mm of precipitation per year, of which 100 mm fall as rain, mainly in the months of June, July, August, and September. Prevailing winds tend to be

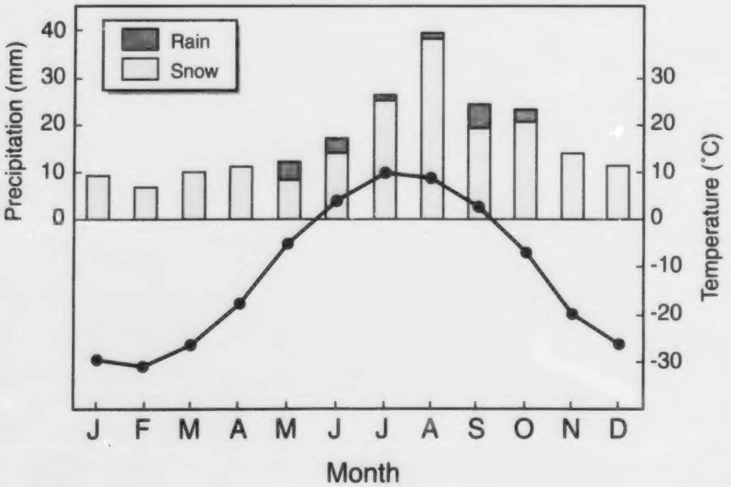

Figure 4.

Climate summary for Kugluktuk, showing monthly mean temperatures (line) and precipitation (bars). Data from Environment Canada (1982).

from the north or northeast in summer, and from the west or southwest in winter. The mean wind speed is about 15 km/hr, but velocities of 50 km/hr are generated by storm winds from the northwest. These winds produce choppy seas, particularly in the shallow water near Kugluktuk.

Terrain

The terrain surrounding Kugluktuk consists of coastal lowlands of sand and clay plains dotted with shallow lakes. A series of bold, elongated, bedrock hills rises abruptly from the lowlands. The cliff-like southern faces and more gently sloping north-facing sides interrupt the monotony of the lowland terrain, and produce a saw-toothed profile on the western horizon. The coastal plain extends inland for a distance of 20–30 km, and rises gently from the coast to an elevation of about 160 m in a series of subtle steps. These steps mark old abandoned shorelines or low terraces of sand and gravel associated with the ancestral Coppermine River. Rolling treeless uplands, consisting of rock and debris from former continent-sized glaciers, characterize the interior.

The Coppermine River originates at Lac de Gras, about 450 km south of Kugluktuk on the tundra barrens, and begins its course as a series of lakes and shallow winding streams. The river has cut deeply through rock and sediment in its middle reaches, between Fairy Lake River and Bloody Fall, creating rock-walled gorges and wider valleys with sides of gullied clay. The river flows through a broad plain near the coast, where river banks are lower and shifting sand bars are common. A major delta marks the entry of the river into the sea. The river delta has six main distributary channels, separated by stable islands, and many shifting sand banks.

But it wasn't always like this…

People of Kugluktuk

Although Kugluktuk was not established as a permanent community until relatively recently, people have lived along the southern shores of Coronation Gulf for thousands of years (McGhee, 1990, 1996). Since early peoples left no written records and oral traditions extend back only a few generations, most of the early history of the people in this region comes from archeological studies, together with a limited amount of data from studies of language evolution and genetics. Many aspects related to the human occupation of this region are therefore imprecise and incomplete.

Pre-Dorset people (4500–2600 years ago or 2500–600 BC)

The first people to arrive in the Coppermine area are known to archeologists as the Pre-Dorset people. Initially, they spread rapidly eastward across the Arctic coast from a homeland on the Alaskan shoreline, but groups later moved inland, as far south as Great Bear Lake, into areas now occupied by Indians.

The Pre-Dorset people of the western Arctic experienced weather conditions somewhat different from today. Summers were more prolonged, and summer temperatures were slightly warmer than at present. Sea ice disappeared earlier, more driftwood reached the shores, and the treeline may have been farther north. The availability of wood and the longer period of open water influenced their lifestyles.

The Pre-Dorset population was low. People were spread out in single-family camps, which were occupied for short periods and then abandoned. Most travel was on foot. The people lived year-round in skin tents, oval in outline, that were heated in winter by wood fires. Wood was also used as cooking fuel. The principal food sources were seals, caribou, fish, and birds. The seals were hunted in winter at breathing holes on sea ice, rather than from boats, which they did not have. Seals were caught using sophisticated harpoons whose stone tips 'toggled' or moved sideways after penetrating the prey. Land animals were hunted with bows and arrows, and lances. Stone knives and scrapers (Fig. 5) were used to prepare food and hides.

Several Pre-Dorset sites near Kugluktuk show that local resources provided the means for living. Argillite and chert, both local rock types, were used to make the blades, points, and knives, excavated from a rocky knoll on the west side of Bloody Fall. These artifacts, and copper barbs, are all that remains of a fishing camp. A radiocarbon date on charcoal from the cooking hearth at Bloody Fall indicates that it was occupied about 3300 ±900 years ago (McGhee, 1970, date reference S-463). Farther inland, near Dismal Lakes, another Pre-Dorset site contains the remains of a caribou hunt.

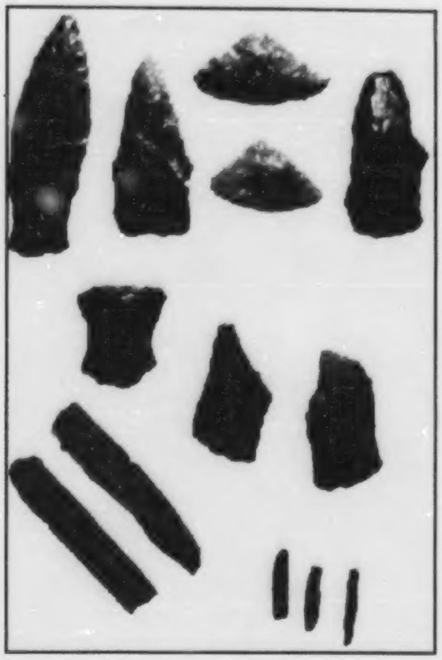

Figure 5. *Tools typical of the Pre-Dorset Tradition: top row, spear points and blades; middle row, scrapers; bottom row, burins and microblades. Photo courtesy of the Canadian Museum of Civilization.*

The coastline of Kugluktuk in Pre-Dorset time differed from that of today. Sea level was as much as 10–15 m higher than at present during the earliest occupation by the Pre-Dorset people, and one branch of the Coppermine River emptied into the sea about 6 km west of the present-day river mouth. The Pre-Dorset shoreline was 3 km inland from the present beach in some places. The islands of the Coppermine River delta did not yet exist, and the terraces forming the east and west banks of the modern river had not yet formed. Rocky parts of the main river-mouth island stood offshore in the sea.

Dorset/Tunit people (2600–1000 years ago or 600 BC to AD 1000)

Lifestyles in Arctic Canada changed as the climate became cooler, probably a few degrees cooler than today. Sea ice remained for much of the summer, providing a stable platform for hunting marine mammals. In the eastern Arctic, a principal source of food was the seal, which was speared through breathing holes in the sea ice. Bone snow knives found at eastern sites indicate that people lived in snow houses on the ice during the long winter, in extended family groups of up to 200 people. Soapstone lamps burning seal oil, rather than wood fires, provided both heat and light. In summer, people lived in skin tents that were rectangular in outline, in communities consisting of several families. In the western Arctic, caribou and musk oxen were an important part of the diet, particularly in summer. Dorset people hunted these animals with spears and lances, rather than the bows of their predecessors. Chert, argillite, and copper were used for blades, knives, and chisels. Despite relatively harsh living and travel conditions, a considerable amount of trade took place between Dorset groups.

The Dorset people are renowned for their carving skills. Masks and delicately carved miniatures of men, animals, weapons, and spirits attest to a rich and creative artistic tradition.

In the Coppermine River area, the Dorset population was sparse and Indian groups occupied the barren grounds at least as far north as Bloody Fall. Small bands of hunters followed migrating caribou and occupied seasonal camps on the high terraces north of Bloody Fall on the west side of the Coppermine River. Points and blades of local basalt, as well as tools of bone and antler, mark their occupation sites.

Thule people (1000–500 years ago or AD 1000–1500)

A new wave of people, the ancestors of modern Inuit, spread rapidly eastward across the Arctic about a thousand years ago and displaced the Dorset people. Most Thule sites are located along sea coasts, although one site is known from Bloody Fall. Lifestyles reflected warmer climates and extended periods of open water at classic sites in the eastern Arctic, where the earmarks of this culture became the 'harpoon with float gear' and large boats that could hold several people hunting in open water. In the east, the Thule people hunted large marine mammals, particularly bowhead whale. In Coronation Gulf, however, whales were not common. Instead, the principal items of diet were seals, which were hunted from the floe edge, and fish, which were speared. Bows found at Bloody Fall suggest a heavy reliance on caribou as well at that site.

The Thule inhabited villages of about 20–50 people. In summer, they lived in skin tents that were oval in plan, or in single-room permanent dwellings that had an excavated floor, sod walls, and a skin roof held up by poles (or whalebones in the east). There was usually a raised sleeping platform at the back. Remnants of two such dwellings with floors of stone slabs were noted by Samuel Hearne at Bloody Fall in 1771. These have since been excavated by archeologist Robert McGhee (1970). Snow houses built on the sea ice were used in winter. There was considerable travel between communities, enabled in part by the use of large sleds pulled by sled-dogs. The presence of iron, copper, and soapstone objects across the Arctic indicates widespread trading.

Sites near Kugluktuk are distinctive for their absence of float harpoons, presence of bowls made of pottery and bark rather than soapstone, and the abundance of copper implements (Morrison, 1983).

Copper Inuit people (500–150 years ago or AD 1500–1850)

About 500 years ago, during the Little Ice Age (a period of climate cooling), the Thule people split into more distinctive local groups, each adapted to the resources in its area. A group known as the Copper Eskimo occupied areas around Coronation Gulf. They numbered about 800 people in all, and led a nomadic life. People spent the winter on the sea ice in snow-house communities of about 100 individuals. Each community built a snow dance-house. The main winter food source was seals, which were hunted through breathing holes cut in the ice, rather than from boats at the floe edge, the method of their predecessors. The Inuit migrated inland in the spring, and dispersed into small groups consisting of a single family or several families. They lived in tent camps, moved frequently, and usually travelled on foot. Fish, the summer mainstay, were trapped in fish weirs constructed across streams and then speared. Caribou were hunted in the fall, using both bows and lances (Fig. 6). On Coronation Gulf, many tools were made of copper derived from copper nodules picked up along the Coppermine River, or from metallic copper extracted from workings about 30 km southeast of Kugluktuk.

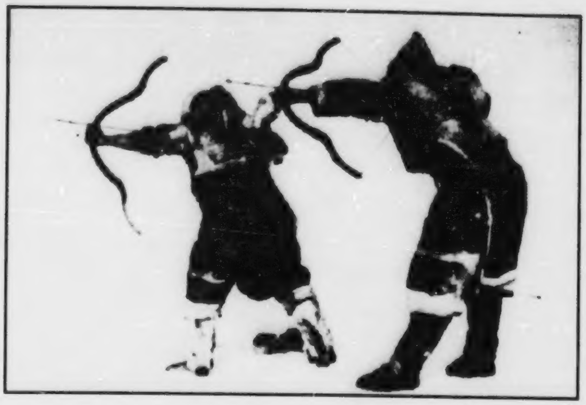

Figure 6. *Bow men of the Copper Inuit Tradition. Photograph courtesy of the National Museum of Canada (photograph 51166).*

Modern period

With the arrival of European explorers and traders, the people of Coronation Gulf witnessed rapid changes. Samuel Hearne, a young clerk with the Hudson's Bay Company, was the first European to explore the Coppermine area. His exploits were prompted by rumours of copper resources so pure and vast that the ore could be dumped directly into boats. In 1771, he and a group of Chipewyan Indians led by Matonabbee travelled overland from Hudson Bay to the Coppermine River, and then down the river to its mouth. His account of the land and its resources includes a description of a massacre of the Inuit by Indians at the rapids he named Bloody Fall, as well as Inuit legends about the existence and sudden disappearance of a copper mine.

The next European visitors were part of the overland expedition of 1819–1822 in search of the elusive Northwest Passage. John Franklin and his party, which included Robert Hood, John Richardson, and George Back, descended the Coppermine River and then proceeded eastward along the south shore of

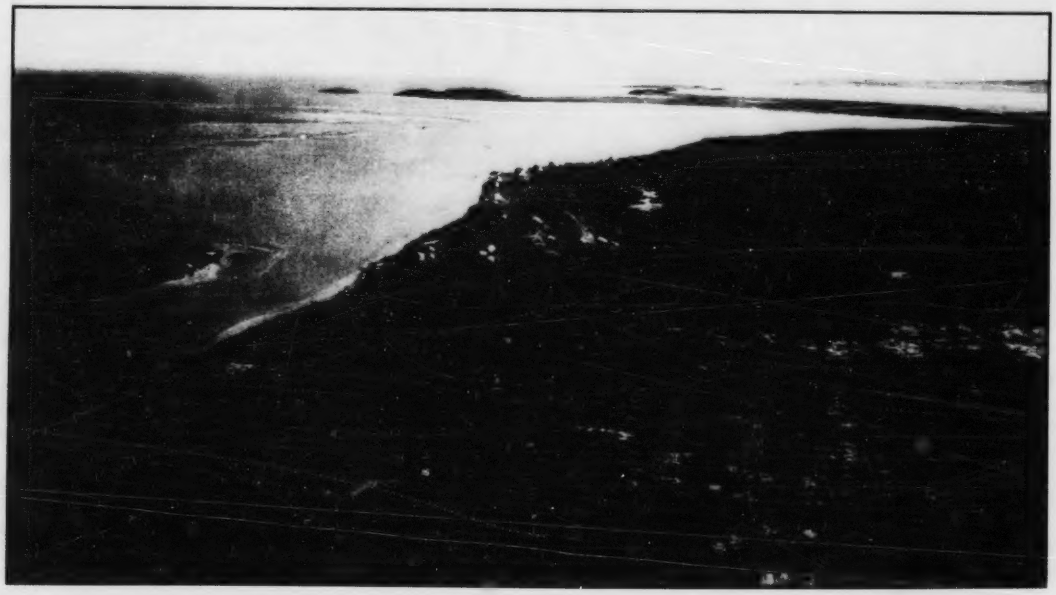

Figure 7. *Settlement of Coppermine (Kugluktuk) in 1930, looking east. The rocks in the foreground are the same as those on the right on the cover photo. NAPL A2743-108*

Coronation Gulf. They were followed by John Richardson, Thomas Simpson, Peter Dease, and John Rae, who also surveyed the coast and river, in part during the long search for the remains of the lost Franklin expedition. Their efforts have been commemorated in the rivers and landforms named after them.

By the early 1900s, the old way of life of the Copper Inuit was fast disappearing. An account of the traditional Inuit culture of the early 1900s has been preserved in the writings of ethnologists, including Diamond Jenness and Vilhjalmur Stefansson. The book *People of the Twilight* by Jenness (1928) is a vivid account of the twilight of the traditional lifestyle. By the time Jenness visited Coronation Gulf, traders and a few whalers (on Victoria Island) had reached the western Arctic. Missionaries also arrived about the same time as the early traders. In 1913, two Oblate missionaries, Fathers Rouvière and LeRoux, were killed by local people a short distance south of Bloody Fall. The ensuing investigation by the Northwest Mounted Police made headlines across the country.

The permanent settlement of Coppermine began with a fur-trading post built by Christian Klengenberg in 1916 at the mouth of the Coppermine River. The Hudson's Bay Company moved its post from Bernard Harbour to Coppermine in 1927. The following year, the Anglican mission, which included a nursing station, also moved from Bernard Harbour, and many Inuit moved into Coppermine at that time. Law and order, in the form of the RCMP, arrived in 1932 (Fig. 7).

Between 1930 and 1960, mineral exploration companies looking for copper sparked a staking rush in the area south of Escape Rapids, but no significant mineral deposits were found. Inuit largely abandoned camp life and moved into the present community by the 1960s, in conjunction with government housing projects and the construction of schools. Most townspeople are presently engaged in government administration, construction, hunting, fishing, oil and gas exploration, carving, painting, and handicrafts. In 1999, the renamed hamlet of Kugluktuk became part of Nunavut Territory.

PART II: A WALK THROUGH TIME

Reading the rocks

Mapping the land

Geological maps contain information on the nature and distribution of earth materials, show relations between one material and another, and suggest the age of each map unit. They are a visual portrayal of the Earth's history. Such maps are based on extensive field work, in which rocks and sediments are examined. The field data are then compiled and plotted on a geographic base. Aerial photographs are commonly used to map the gaps between field observation points to make a finished map.

Once the landforms and materials have been mapped and their characteristics (such as shape, lithology, and structure) studied, we can begin to interpret their origins. The present is a key to the past: in many cases, processes that are operating today also operated in the past. By looking at characteristic materials associated with present rivers, oceans, glaciers, and volcanoes, for instance, we can identify similar characteristics in the rocks and infer that similar processes formed them.

When we have determined the processes that formed a particular rock or sediment, and mapped the relationships that exist between one material and another, we can reconstruct the sequence of events that produced the landscapes we see today. From these maps, detailed field observations, and a healthy dose of creative imagination, we can recreate in our minds at least a part of the Earth's history.

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Who cares?

By understanding the geology of an area, we develop a better idea of how our land evolved, how we fit into it, and how we affect it. Also, by understanding the processes that formed the land, we can develop models to predict where various resources, such as minerals and aggregate, might be found. We can predict what is in areas for which we have no first-hand information, how the land will behave in response to changing climates or land-use practices, and where hazardous conditions prevail. With an understanding of the processes that formed our present environment, and the types and rates of change that are occurring at present, we can care for it better.

Dating the past

One problem with interpreting the earth's history is determining when events occurred. After all, nobody was around to record them. Dating events can be done in two ways: relative dating, where a sequence of events can be established, and absolute dating, in which real years are assigned to events or rock units.

Relative dating

Rocks or sediments (unconsolidated materials) can be put in order of their relative ages by examining the relationships between them and seeing which units overlie others. In general, the uppermost units have been deposited on top of older ones, and are therefore younger. Using this principle, a sequence of events can be interpreted once the order of deposition has been established. Dating using fossil types, a variation of the relative dating method, is based on comparing fossils from a locality where the rock age is unknown to one with similar fossils where the rock age (or succession) is known. Basically, units with the same kinds of fossils are correlated and assumed to be the same age.

Absolute dating

The second type of age determination gives an 'absolute' age for rocks or sediments, in that it is an indication of the actual number of years that have passed since the rock or sediment formed. Most materials, including people, contain small amounts of radioactive isotopes that 'decay' or change into other elements at a known rate. By measuring the amounts of these isotopes and their stable end products in rocks, ages can be back-calculated. For example, the commonly used potassium/argon method compares the amount of radioactive potassium in feldspar grains in rock with the amount of its decay product, argon. The radiocarbon method, in which the amount of radioactive carbon-14 is compared with the amount of stable carbon-12, is commonly used in younger sediments.

Geological time scale

A time scale for the Earth is shown in Figure 8. The ages and names of geological intervals are shown on the left, and the rocks and sediments in the Coppermine area that fit into these categories are shown on the right.

One of the most difficult ideas for us to grasp is the immensity of geological time. The oldest rocks are more than 4 billion years old, a number that is beyond comprehension. If we think of all geological time as a 24-hour day, then human beings come on the scene in the last 20 seconds, and our own life spans happen in the last 1/1000 of a second in that day.

Geological record

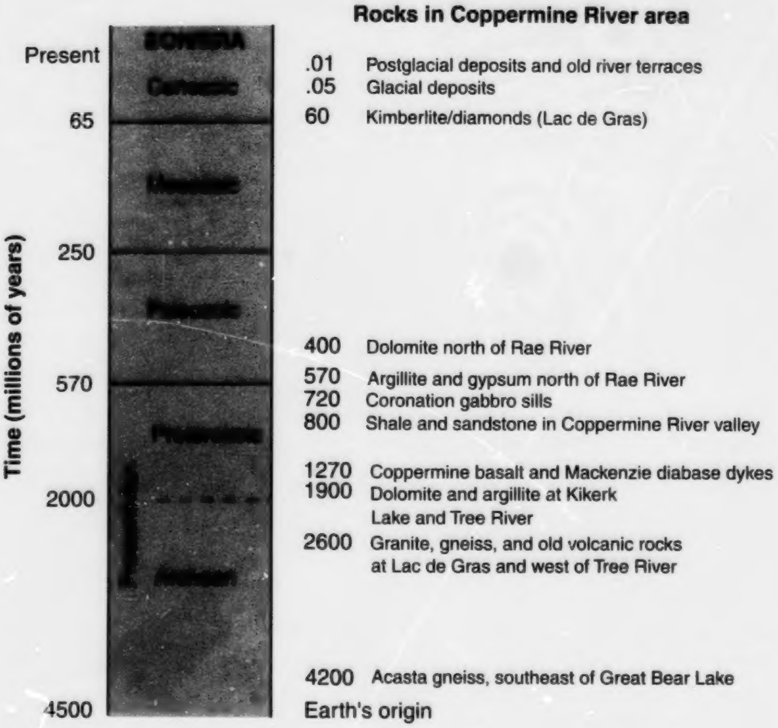

Figure 8. *Geological time scale, with the time of formation of rocks in the Coppermine River area shown on the right.*

Most rocks of the Coppermine River area lie in the northwestern corner of the Precambrian Canadian Shield (Fig. 9), which forms the ancient rock core of much of North America. The oldest rocks on Earth, called the Acasta Gneiss, are found southeast of Great Bear Lake, not far from this region. They are about 4.2 billion years old, and are the remnants of small protocontinents that developed when the earth's outer surface began to form a crust. Somewhat younger rocks, ranging in age from 2.5 to about 3 billion years and forming a major part of the old land mass recognized as the Canadian Shield, underlie the area of Lac de Gras, the headwaters of the Coppermine River, and the land west of Tree River. These younger rocks are mainly granite, which formed as molten magma deep within the earth, volcanic rocks, and gneiss, which resulted when older rocks were metamorphosed (changed) by intense heat and pressure within the earth.

The rocks of the lower Coppermine River are much younger, less than 1.5 billion years old. These formed by volcanic eruptions that spewed out magma originating from deep within the earth. Later, the edges of what was then the continental margin subsided, and a thick sequence of sediments was deposited in the sea at its depressed edge. These rocks now form part of the Bear Structural Province in the northwestern part of the Canadian Shield.

The rocks north of the Rae River are Paleozoic in age, about 500 million years old. They formed as sediments that were deposited in more recent, shallow ocean basins at the edge of the shield. These basins are known as the Interior and Arctic platforms, and they are the main areas of interest in oil exploration.

The final stages in the geological record of the Coppermine River area began with glaciers that covered most of the Canadian landmass between 2 million years ago and 10 000 years ago, and eroded the surfaces of the rocks, leaving a cover of gravel and ground-up rock debris (called 'till') after they melted. Many of the sediments near Kugluktuk were deposited in high-level seas that existed in the last 10 000 years, after the ice ages. Erosion and deposition of rock and sediment continue today, as the Coppermine River cuts through older rocks and deposits its sediment load in Coronation Gulf.

+9

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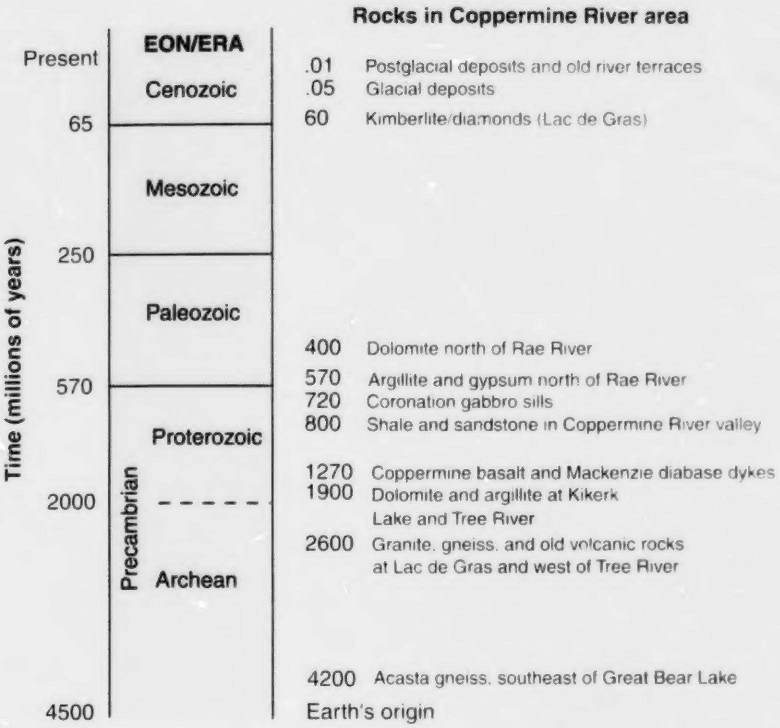
Rocks in Coppermine River area
EON/ERA
Present
Cenozoic
65
Mesozoic
250
Paleozoic
570
Proterozoic
2000
Precambrian
Archean
4500
Time (millions of years)
.01 Postglacial deposits and old river terraces
.05 Glacial deposits
60 Kimberlite/diamonds (Lac de Gras)
400 Dolomite north of Rae River
570 Argillite and gypsum north of Rae River
720 Coronation gabbro sills
800 Shale and sandstone in Coppermine River valley
1270 Coppermine basalt and Mackenzie diabase dykes
1900 Dolomite and argillite at Kikerk Lake and Tree River
2600 Granite, gneiss, and old volcanic rocks at Lac de Gras and west of Tree River
4200 Acasta gneiss, southeast of Great Bear Lake
Earth's origin

Figure 8. *Geological time scale, with the time of formation of rocks in the Coppermine River area shown on the right.*

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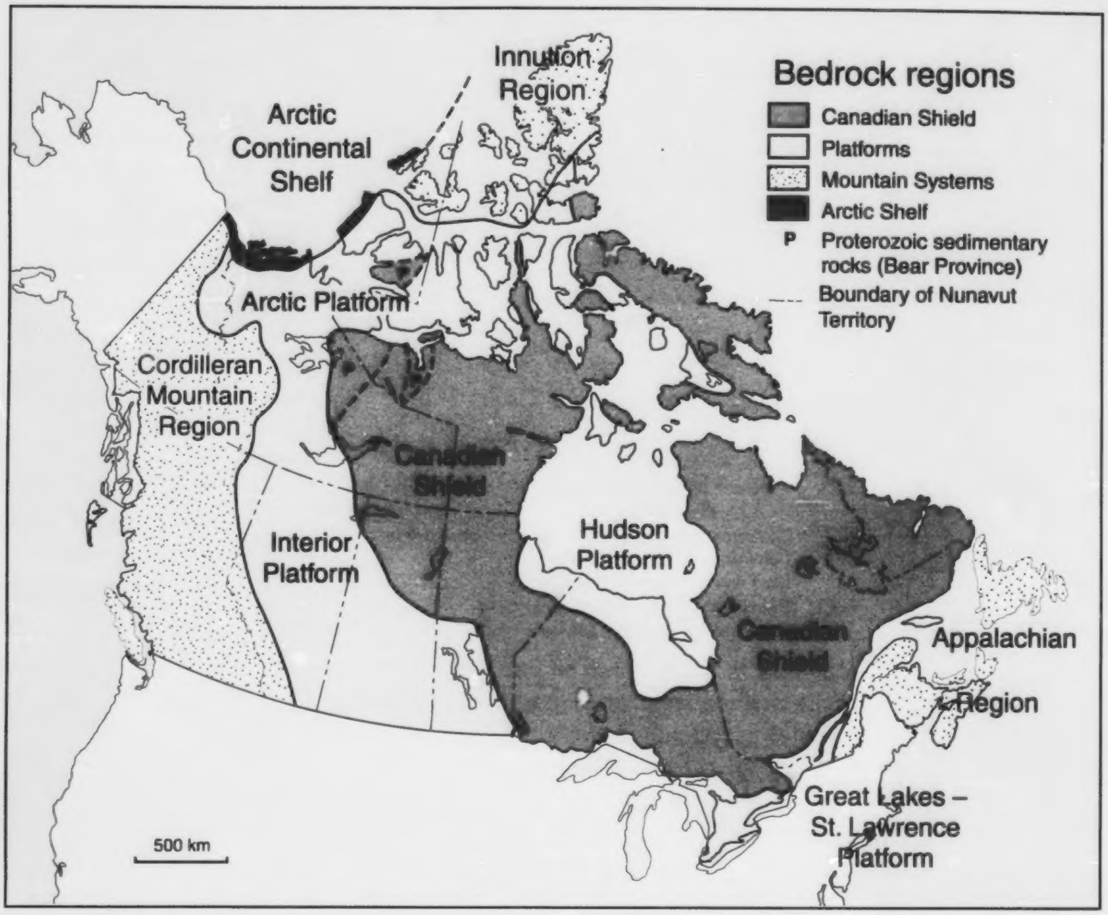

Bedrock regions
▨ Canadian Shield
☐ Platforms
▨ Mountain Systems
■ Arctic Shelf
P Proterozoic sedimentary rocks (Bear Province)
--- Boundary of Nunavut Territory
Innuitian Region
Arctic Continental Shelf
Arctic Platform
Cordilleran Mountain Region
Canadian Shield
Interior Platform
Hudson Platform
Canadian Shield
Appalachian Region
Great Lakes – St. Lawrence Platform
500 km

Figure 9. *Geological regions of Canada. Kugluktuk lies within the Bear Province at the northwestern edge of the Canadian Shield. The area north of the Rae River is part of the younger Arctic Platform.*

The maps on the following pages show the nature and distribution of bedrock types and surface materials. These maps, along with airphoto interpretation and ground observations, were used to interpret the geological history presented below.

Ancient history: bedrock geology

Bedrock geology map

Figure 10 is a bedrock geology map showing the main types of rocks in the Coppermine River area. The relative ages of the rocks are shown on Figure 8.

Rock unit 1 (Copper Creek formation) consists of huge coalescing lava plains that formed as magma (molten rock) erupted from fissures or vents in the earth's crust about 1270 million (i.e. 1.27 billion) years ago. There are about 150 eruptions, or lava flows, recorded here in the rock record. These lava flows are composed of fine-grained basalt, an igneous rock made up of the minerals plagioclase, pyroxene, and

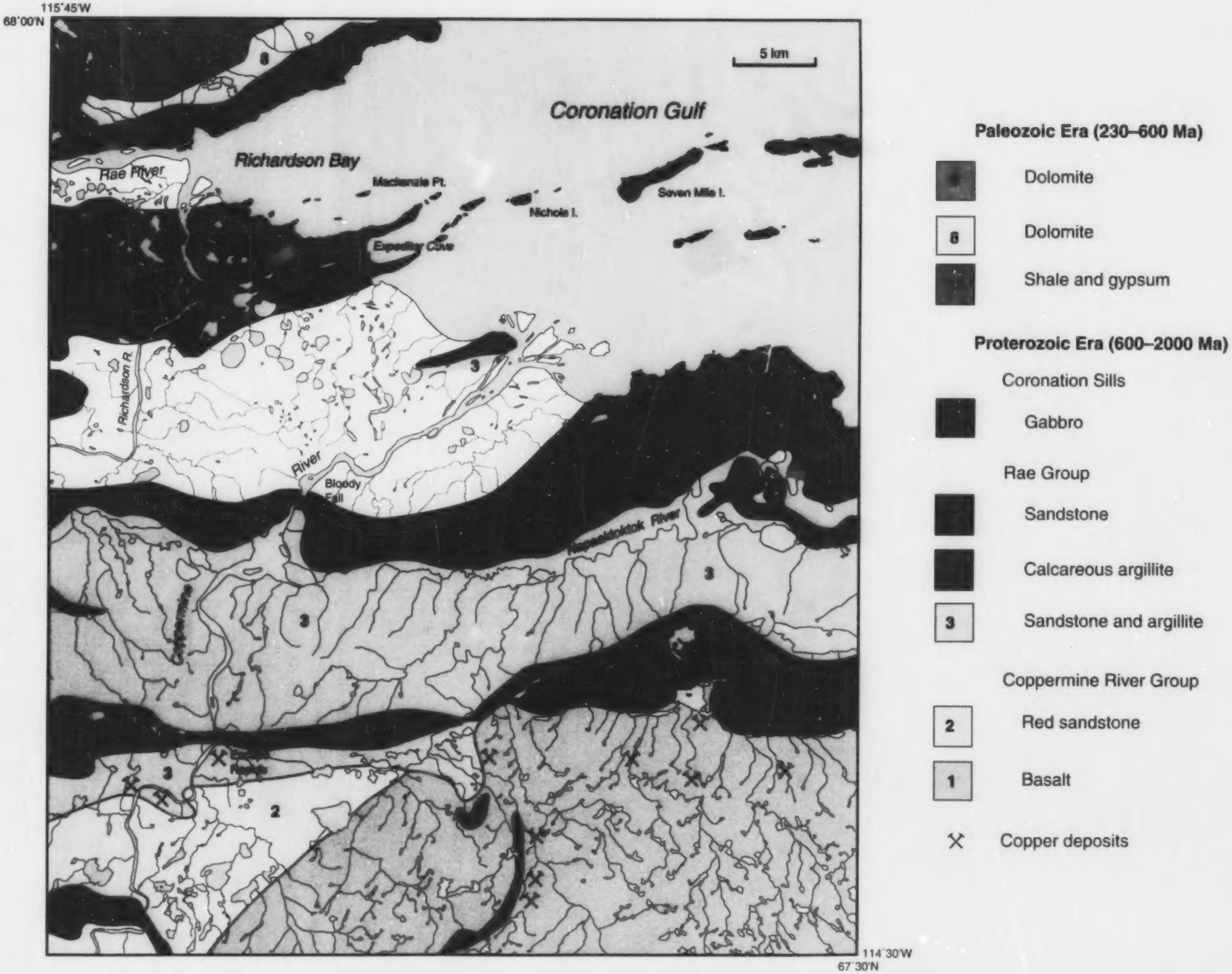

115°45'W
68°00'N
114°30'W
67°30'N
5 km
Coronation Gulf
Richardson Bay
Rae River
Mackenzie Pt.
Nichols I.
Seven Mile I.
Expedition Cove
Richardson R.
River
Bloody Fall
Napaaktoktok River
Coppermine
8
3
2
Paleozoic Era (230–600 Ma)
Dolomite
8 Dolomite
Shale and gypsum
Proterozoic Era (600–2000 Ma)
Coronation Sills
Gabbro
Rae Group
Sandstone
Calcareous argillite
3 Sandstone and argillite
Coppermine River Group
2 Red sandstone
1 Basalt
⚒ Copper deposits

***Figure 10.** Bedrock geology, Coppermine region* (after *Baragar and Donaldson, 1973*). *The abbreviation 'Ma' means 'million years'.*

magnetite. Where they are exposed in cliffs along the river, each lava layer can be seen to be massive at the bottom, but with small air holes, which were once filled with volcanic gases, at the top. Most of the copper comes from the lower massive part of each lava flow. The Mackenzie diabase dykes, which form thin, dark ridges trending northwest-southeast across the upland plains to the south of the area shown in Figure 10, are contemporary with the lava.

Toward the end of the period of volcanic eruptions, the solidified lava and other rocks were being eroded, transported, and eventually deposited by rivers. These sedimentary rocks, which form rock unit 2 (Husky Creek formation), are interlayered with and overlie the lava. The rock is a reddish sandstone, best exposed near Sandstone Rapids. The sandstone consists of sand-sized grains of quartz, coated with iron oxide (rust), which gives the rock its reddish colour. The sandstone has criss-crossing structures (crossbedding), showing that it was deposited by variable river currents.

The land was then uplifted and eroded, and there is a long interval for which the rock record is missing.

Rock unit 3 (lower Rae Group) consists of much younger rocks, about 800 million years old, that were laid down as sediments in an ancient sea along the edge of the old continent. These rocks are exposed upstream of Bloody Fall. Gritty sandstone formed where layers of coarse-grained sediments were deposited in shallow water under the influence of waves. Old ripple marks can be seen on some rocks. Grey-black units of siltstone or argillite, made up of fine particles of silt or clay, were deposited between the sandy layers during times when the water was deeper and calmer. The original sediment layers, still visible in these rocks, can be viewed beneath the cliffs on the west side of the hamlet.

Rocks of unit 4 (upper Rae Group), west and north of Kugluktuk, are similar to the fine-grained rocks of unit 3 but contain more dolomite (calcium-magnesium carbonate) and are somewhat softer. Long, continuous beds of these greyish rocks are exposed along the headlands jutting into 4-Mile bay and Expeditor Cove, and on Seven Mile Island. The rocks contain lenses and blazes of white chert, a hard rock composed of silica. Layers with stromatolites, the remains of primitive blue-green algae that grew when the climate was much different than at present, form ledges at the rapids on Rae River. Modern algal mounds of this sort presently grow in shallow tidal pools in tropical seas. The rocks of unit 4 become coarser to the north, and grade upward into thickly bedded quartz sandstone (unit 5) that shows ripple marks and crossbedding. The sandstone was deposited following a period of uplift and renewed erosion, which brought coarse sandy sediments into the edge of the marine basin (Fig. 11).

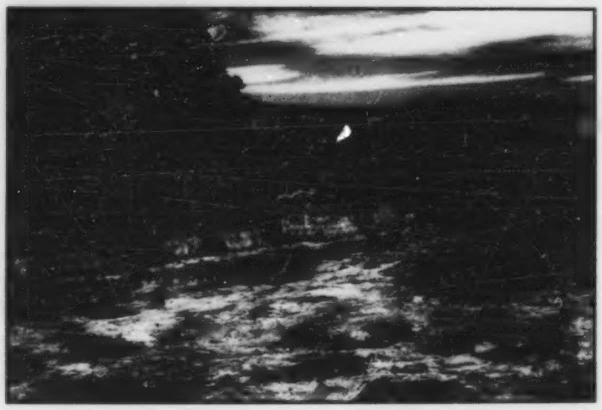


***Figure 11.** Bedrock exposures at the rapids on Rae River. Layered sedimentary rocks of the upper Rae Group are shown in the foreground. Gabbro sills that were intruded into these rocks form the cliff in the background. Photograph by L.A. Dredge. GSC 2000-012C*

About 720 million years ago, the escarpment- and cuesta-forming rocks known as the Coronation Sills (unit 6) developed where magma was intruded into the sedimentary rocks of units 3 through 5. Some of the rocks that form the sills are slightly magnetic. The sills are composed mainly of granular, dark gabbro, but have finer textures near their contacts with the sedimentary rocks they invaded. The hot magma has also altered or 'cooked' some of the sedimentary rocks. Veins of white pectolite, a calcium silicate mineral with a radiating crystal structure, are present within the gabbro on some offshore islands.

At the beginning of the Paleozoic era, the continents began to founder and subside, possibly due to regional faulting. Areas north of the Rae River are characterized by rocks deposited in the resulting shallow seas that formed major sedimentary basins flanking the Canadian Shield. Fine-grained marine sedimentary rocks containing primitive marine fossils (brachiopods) form the red and greenish argillite of unit 7 (Campbell, 1983). Small polygonal mud cracks are visible on the upper surfaces of layers within these rocks. Cubic halite (salt) casts and beds of massive orange gypsum, another salt resulting from the evaporation of seawater, occur in some places within the unit. The uppermost rock unit in this suite of ancient sedimentary rocks is a thick unit of cream-coloured dolomite (unit 8) containing stromatolites.

The youngest rocks shown on the map, unit 9, were deposited much later, about 440 million years ago, after a long period of erosion for which we have no record. These calcareous rocks are dolomite (calcium-magnesium carbonate), made up, in part, of finely ground-up remains of tiny marine animals. The original layers of sediment, now lithified (i.e. turned to rock), are still horizontal, so that the rocks form stepped flat ledges, and break apart into thick plates or slabs. Thin layers of hard silica in this rock are responsible for the rough weathering surfaces (Fig. 12).

There follows a long time interval for which there is no record in the Coppermine area. During this time, the sedimentary rocks overlying the gabbro sills were eroded, leaving the hard sills as cap rocks protecting the softer, underlying argillite and sandstone from erosion. The sills form the long prominent ridges that slope gently downward toward the north, so that their southern faces form escarpments up to 130 m high (Fig. 13).

Copper and carving stone

Copper deposits have been sought after in this area for thousands of years. Both the Thule people and the Copper Eskimo used and traded copper artifacts. The remains of some early workings lie 30 km southeast of Kugluktuk. Accounts of

Figure 12. *Aerial view of stepped ledges of Paleozoic dolomite forming flat, bare surfaces north of the Rae River. Individual blocks that have broken away from the edges of each ledge are up to 10 m across. Photograph by L.A. Dredge. GSC 2000-012D*

Figure 13.

Terrain on the coastal lowlands west of Kugluktuk consists of vegetated sand or clay plains that are interrupted by long, northward-sloping ridges (cuestas) of light-coloured sedimentary rocks, capped by dark-coloured gabbro sills. Photograph by L.A. Dredge. GSC 2000-012E untold wealth in copper attracted Samuel Hearne to the area in 1771; in his journal, he related stories about a copper mine in the area. He also collected nuggets weighing up to 2 kg during his travels. Native copper (pure copper) is one of the minerals in the lavas of rock unit 1, and copper finds are shown by crosses on the geology map (Fig. 10). Most of these are copper flakes, but copper sulphide minerals such as chalcocite (copper sulphide), chalcopyrite (copper-iron sulphide), and bornite (copper-iron sulphide) have also been reported, especially in calcite veins along fractures within this rock unit. Nuggets have been collected from the base of the cliffs along the Coppermine River south of Escape Rapids. Despite the widespread occurrence of copper, concentrations are so low that no commercial operations have been successful. The abandoned core shack and nearby buildings at Hope lake (near Dismal Lakes) are a reminder of one such attempt at copper exploration.Thin sheets of calcite, some with green copper stains, occur as fracture-fillings in argillite where these rocks have been altered by the intrusion of magmas related to the gabbro sills. Disseminated chalcocite is also present in argillite directly below the sills at Kugluktuk.

Carving materials in this area include basaltic lava and gabbro, which have been altered to 'soapstone' by contact metamorphism, and some of the dolomitic argillite near the Richardson and Rae rivers, which are softer and less splintery than the sedimentary rocks along the Coppermine River. The gypsum (alabaster) associated with rock unit 7 north of the Rae River is a source of soft carving material.

Main rock landforms at Kugluktuk

Sedimentary rocks, composed of layers or strata of sandstone or fine-grained argillite, underlie the gabbro sills near Kugluktuk, where they can be seen as outcrop. The sills have protected these rocks from erosion. Sedimentary rocks also underlie lowland areas. Stepped ledges are common landscape forms that mark breaks in the strata in limestone bedrock north of the Rae River.

Sills form prominent ridges along the coastal plain. They formed where magma moved upward from a chamber of molten rock deep within the earth and was injected along the bedding surfaces of sedimentary rocks as horizontal sheets. The weaker sedimentary rocks on top of the sills were eroded away, leaving the more resistant sill intrusions as surface forms.

Giant's staircases are formed of prismatic columns of gabbro (columnar gabbro) and basalt produced by the cracks (joints) that resulted when these rocks cooled down from a molten state and contracted. Columnar gabbro can be viewed along the outer extensions of the peninsulas surrounding Expeditor Cove and on the ridge at the gabbro quarry (*see* Part IV, Stops 18, 34).

Topples develop where bedrock breaks off from a cliff face due to widening of fractures or joints behind the cliff, with resultant outward rotation of the outer rock mass. The rotated rock topples when its centre of gravity projects far enough beyond the cliff. Frost action may be involved in widening the joints and forcing the blocks outward.

Ice-age legacy

Processes at work

Many ice sheets have come and gone in the last 2 million years. During the most recent ice age, which began about 75 000 years ago and reached its peak about 18 000 years ago, much of Canada was covered by a continental ice sheet that had several coalescing centres of outflow (Fig. 14). The passage of glaciers during the ice ages has altered the bedrock topography and shaped the landscape we see today. Glaciers scoured and

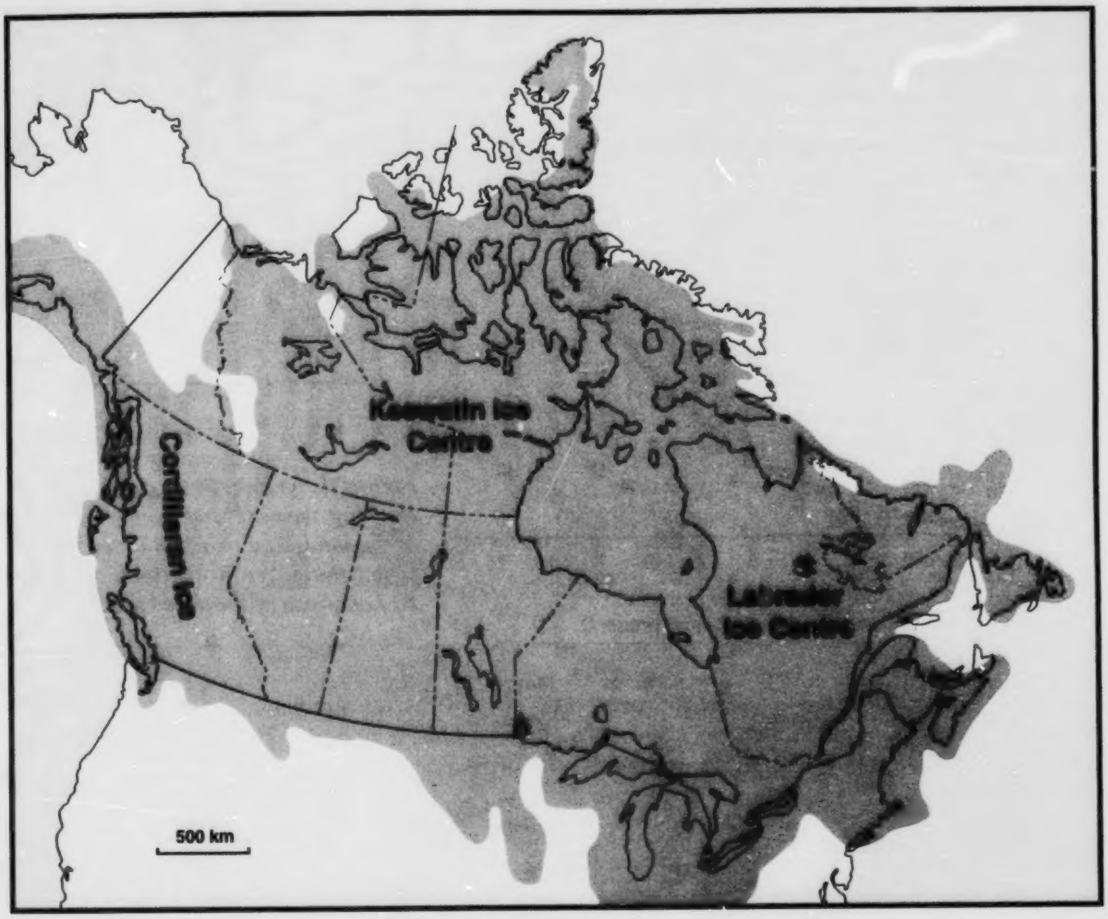


Figure 14. *Extent of the Laurentide Ice Sheet about 25 000 years ago, and main subregions within the ice-sheet complex* (after *Dyke and Prest, 1987*).

eroded the deeply weathered ancient bedrock, leaving behind scratched or polished fresh rock surfaces. They also transported the eroded debris and deposited it when the ice sheets melted, leaving a suite of new landforms.

The weight of the glaciers depressed the Earth's crust so that, near the present coast, the sea flooded in as the glaciers retreated. Thick layers of sediment were deposited into these seas, both directly from the melting ice margin and from rivers. Fine-grained sediments were carried offshore into deep, quiet water, while coarser materials were deposited in shallower water near the shore. As the land adjusted to the removal of the ice load by rebounding, the sea drew back. As the sea regressed, waves reworked the offshore deposits and covered them with a layer of coastal sand. The emerged marine deposits were later incised and reworked by rivers flowing and downcutting on their way to the receding and lowering coast.

The rate of crustal rebound, and therefore the rate of emergence of the land from the postglacial sea, was most rapid immediately after deglaciation, but has continued at a slower rate since then. Figure 15 is a graph that plots the elevation of various shoreline features on the vertical axis, against their age on the horizontal

+1

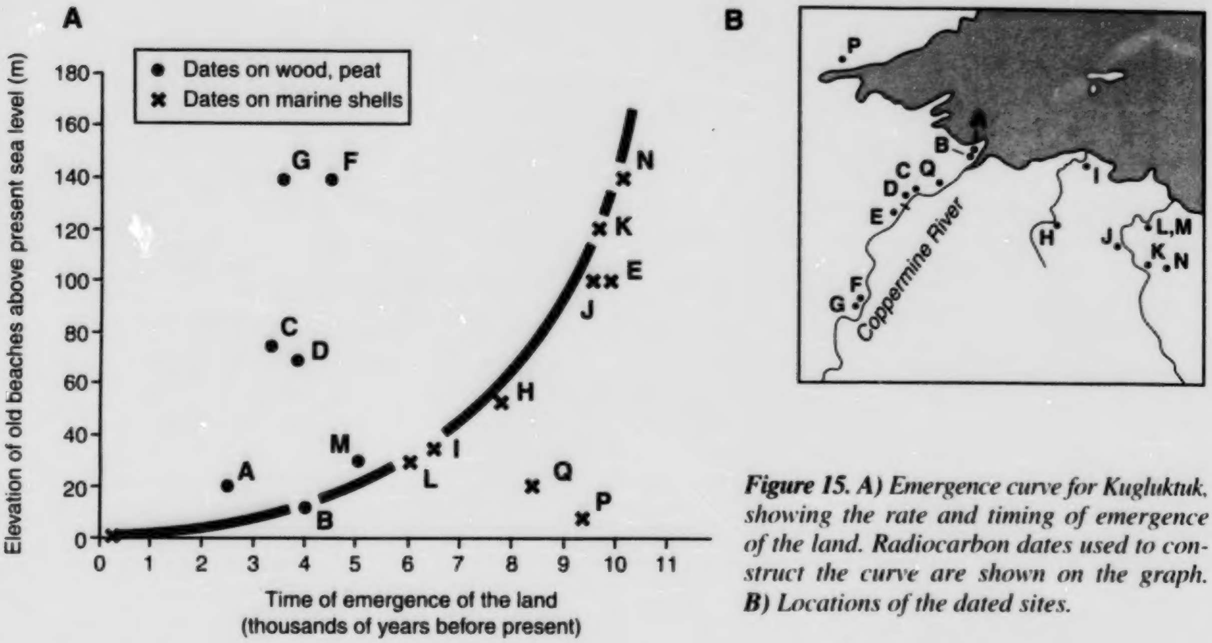


Figure 15. ***A)*** *Emergence curve for Kugluktuk, showing the rate and timing of emergence of the land. Radiocarbon dates used to construct the curve are shown on the graph.* ***B)*** *Locations of the dated sites.*

axis. The ages were determined from the radiocarbon dating of marine shells and driftwood. The resulting pattern, presented as a generalized curve, shows how sea level has changed over the last 10 500 years. The land is still rebounding and emerging from the sea, at a present rate of about 20–50 cm per century.

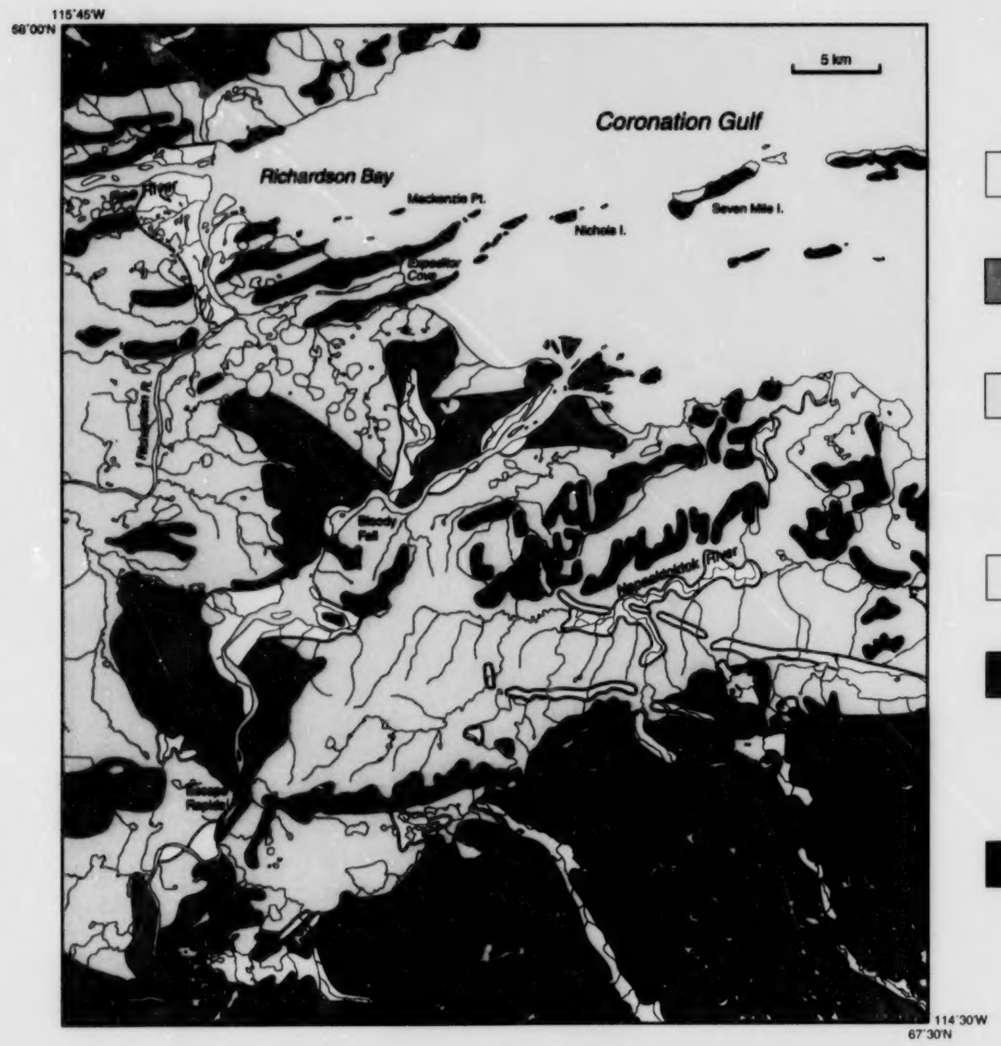
Glacial landforms

Most large-scale landforms produced by glacial deposition begin south of Bloody Fall, in areas that were not covered by postglacial seas. Near Kugluktuk, however, several glacial rock erosion landforms can be seen.

- **Till plains**, composed of glacially ground-up rock debris, start about 30 km south of Kugluktuk.
- **Drumlins** are streamlined landforms formed beneath ice sheets and composed of glacial debris and sediments. Drumlins lie inland from the Asiak River east of Kugluktuk, and on the uplands north of the rapids on Rae River.

Figure 16.

Roche moutonnée landforms. Glaciers flowing eastward (to the right) have smoothed and polished the left side of the bedrock outcrop, and plucked large blocks from the right side. Photograph by L.A. Dredge. GSC 2000-012L


115°45'W
68°00'N
5 km
Coronation Gulf
Richardson Bay
Rae River
Mackenzie Pt.
Nichols I.
Seven Mile I.
Expeditor Cove
Richardson R.
Bloody Fall
River
Escape Rapids
114°30'W
67°30'N

Postglacial deposits

☐ Alluvium

Sand and gravel; forms terraces, bars and shoals

Deposits of glacial seas

▨ Deltaic deposits

Sand and gravel, grading downward to silt and clay; forms broad wedge-shaped terraces incised with small channels

☐ Marine deposits

Silt and clay, capped by sand; locally with fossils; may contain ground ice; forms a gently sloping coastal plain

Glacial deposits

☐ Glaciofluvial deposits

Sand and gravel; forms ridges (eskers), terraces (outwash), and irregular hummocks (kames)

■ Till

Unsorted stony sand or stony silt; forms undulating discontinuous blanket deposits over bedrock

Bedrock

■ Rock outcrop

Mainly gabbro and basalt, some shale and dolomite; forms ridges and talus slopes

Figure 17. *Surface materials, Coppermine region* (modified from *St-Onge, 1988; Kerr et al., 1997*).

- **Eskers** are sinuous ridges of sand and gravel that developed where meltwater flowed in a channel within or beneath the glacier.
- **Outwash plains** develop where streams flowing within a glacier reach the ice front and deposit their sediment. Most outwash plains are composed of gravel. Outwash deltas form where the sea abutted the ice front.
- **Erratics** are individual, boulder-sized rock fragments that have been transported by glaciers and deposited in areas underlain by a different rock type.
- **Whaleback features** develop on bedrock where glaciers eroded around irregularities in the rock, carving streamlined forms, several metres high, on the rock surface.
- **Roches moutonnées** develop where the glacier has smoothed and streamlined the whaleback in the up-ice direction, but has plucked off and eroded part of the rock mass in the down-ice direction (Fig. 16).
- **Striations** are scratch marks on rock surfaces, produced where pebbles embedded in the base of the passing glacier were dragged across the bedrock. The direction of the scratches indicates the direction of glacier flow. Microscratches create highly polished surfaces of fresh rock that can have a dazzling, mirror-like surface. Crossing striations indicate that ice has flowed from more than one direction at various times.
- **Glacier facets** are small, remnant, planar features on bedrock, produced where a glacier eroding rock in one direction has shaped a rock, and then a glacier flowing in another direction has reshaped the rock, leaving part of the older surface intact.

Surficial geology maps

The main materials that make up the present landscape in the Coppermine region are shown on the regional surficial materials maps (Fig. 17, 18). Figure 19 is a more detailed map of features near Kugluktuk. Most materials are the product of the ice ages and subsequent marine episodes, but bedrock outcrops, described previously, protrude through the ice-age sediments in several places.

Till covers the southern parts of the regional map (Fig. 17). In some places, the till cover is thin and bedrock outcrops poke through (Fig. 20); in other areas, it forms a thick blanket with low ridges (drumlins) elongated in the direction of ice flow (Fig. 21). Till consists of the rock debris that was eroded, transported, and later deposited by glaciers. Its character depends on the rock over which the glacier has passed; in this area, it forms a stony, unsorted material with a sandy to silty matrix. Its composition reflects the granite and dolomite bedrock that lies far to the south, and sandstone, shale, and basalt from local sources.

Glaciofluvial deposits, shown in yellow, are sinuous ridges of sand and gravel (eskers) that snake across the till surface (Fig. 22, 23). They are the remains of sediment-laden glacial meltwater channels that flowed within or at the base of the ice sheet. The eskers, and related gravelly fans of material carried by glacial meltwater (outwash), are generally good sources of aggregate.

Postglacial marine deposits cover most of the map (Fig. 17). The surface is commonly a blanket of sand, often shaped into low, undulating, gravelly beach ridges (Fig. 24). There are ice-wedge polygons and other frost cracks on some sand surfaces.

Thick deposits of finer silt and clay, the result of deposition in deep, quiet water, commonly underlie the sand (Fig. 25). These deposits also are exposed in the bluffs along the Coppermine River, both above and below Bloody Fall. Their fine texture restricts drainage and promotes the growth of ground ice. Erosion or disturbance of these sediments can lead to landslides or slope failures. Crescentic outlines along river banks show where gullying or landslides have occurred in the past.

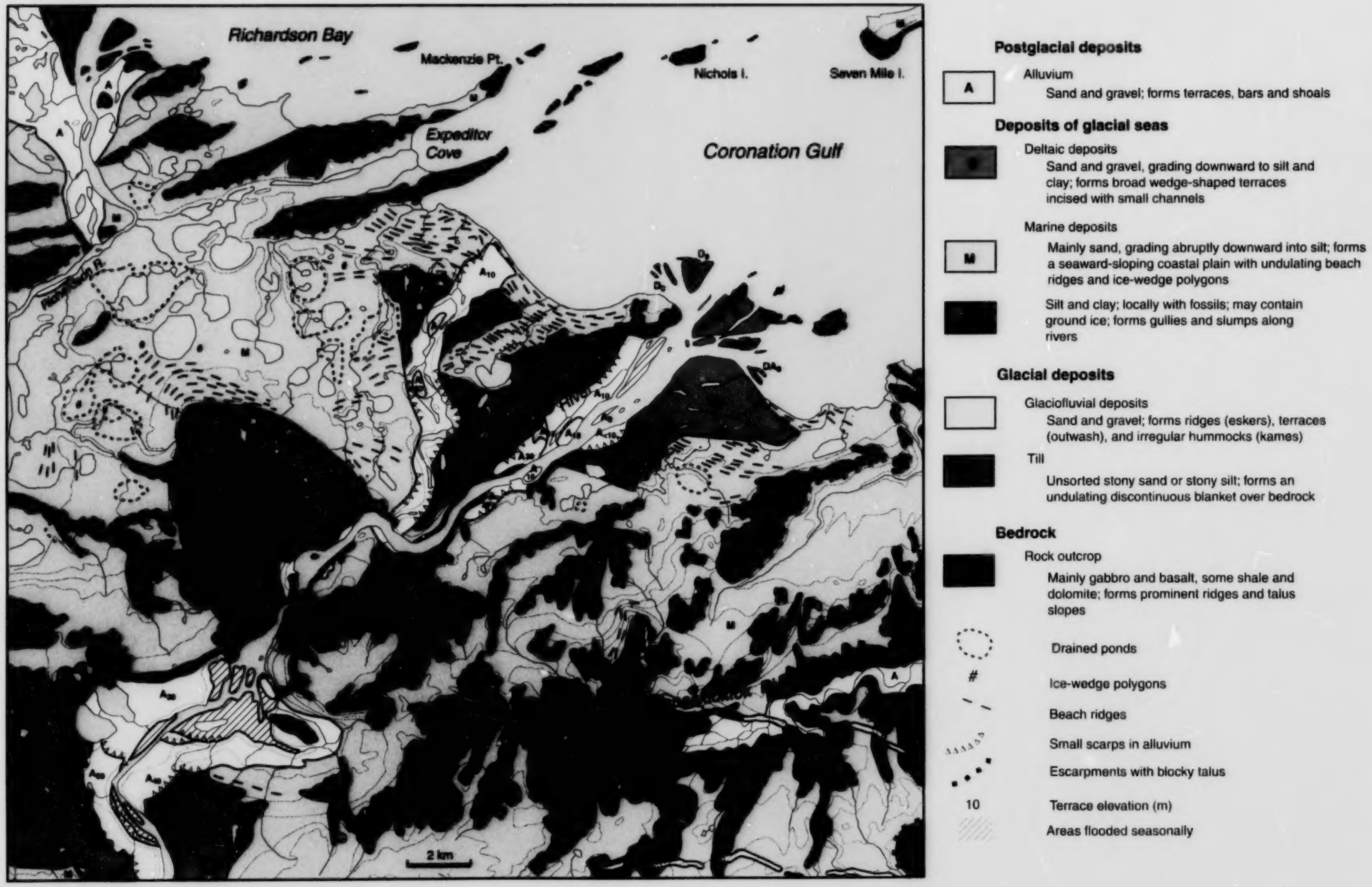

Richardson Bay
Mackenzie Pt.
Nichols I.
Seven Mile I.
Expeditor Cove
Coronation Gulf
Richardson R.
A
M
A10
2 km
Postglacial deposits
A
Alluvium
Sand and gravel; forms terraces, bars and shoals
Deposits of glacial seas
Deltaic deposits
Sand and gravel, grading downward to silt and clay; forms broad wedge-shaped terraces incised with small channels
Marine deposits
M
Mainly sand, grading abruptly downward into silt; forms a seaward-sloping coastal plain with undulating beach ridges and ice-wedge polygons
Silt and clay; locally with fossils; may contain ground ice; forms gullies and slumps along rivers
Glacial deposits
Glaciofluvial deposits
Sand and gravel; forms ridges (eskers), terraces (outwash), and irregular hummocks (kames)
Till
Unsorted stony sand or stony silt; forms an undulating discontinuous blanket over bedrock
Bedrock
Rock outcrop
Mainly gabbro and basalt, some shale and dolomite; forms prominent ridges and talus slopes
Drained ponds
#
Ice-wedge polygons
Beach ridges
Small scarps in alluvium
Escarpments with blocky talus
10
Terrace elevation (m)
Areas flooded seasonally

Figure 18. Detailed map of surficial geology near Kugluktuk (based on airphoto interpretation and ground observations).

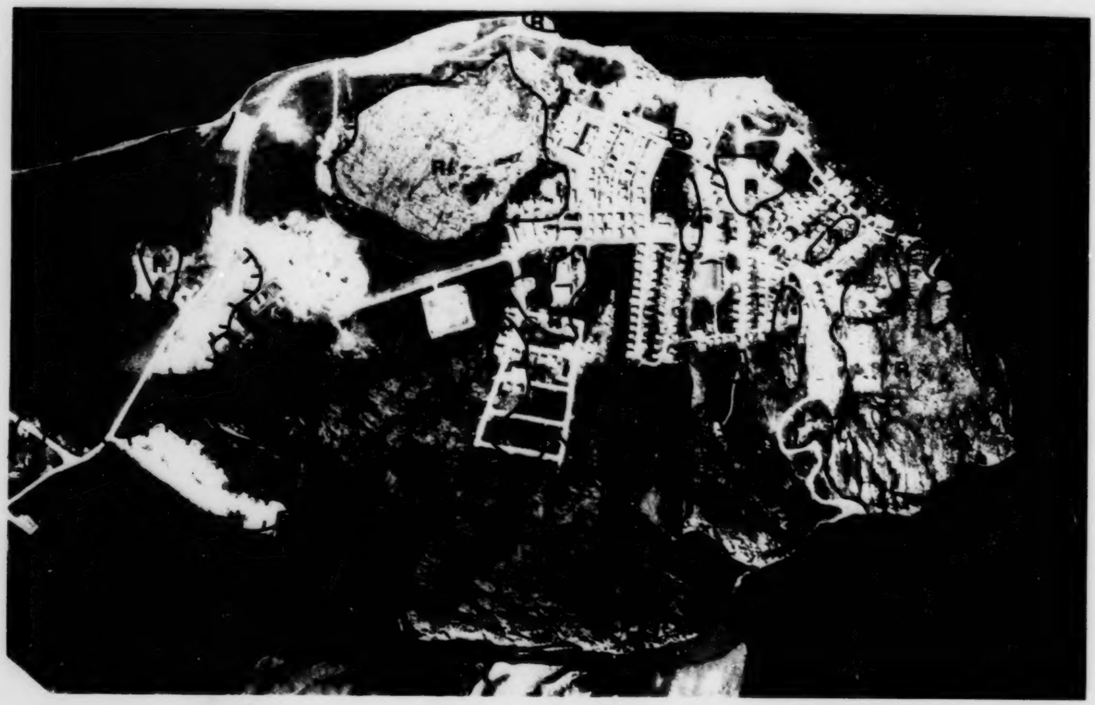

R
R Gabbro bedrock
S Sand
M Thin deposits of sand and clay overlying rock
Argillite quarries

Figure 19. *Distribution of rock and sediment at Kugluktuk (based on airphoto interpretation and ground observations). NAPL A 27935-78*

Figure 20. *Till plains near Asiak River, about 30 km inland from the coast, with glacially smoothed bedrock outcrops in the foreground. Pond is approximately 10 m long. Photograph by L.A. Dredge. GSC 2000-012F*

Figure 21. *Field of drumlins northwest of Klengenberg Bay. These glacial landforms are composed of rock fragments that have been ground up, transported, and finally deposited by glaciers. The landforms are elongated in the direction of ice flow, in this case toward the west (left). Some of the drumlins are more than a kilometre long. Photograph by S.A. Wolfe. GSC 2000-012G*

Figure 22. The winding ridge in the centre of the photo, extending westward into the background, is an esker. This ridge of sand and gravel developed when channelled meltwater, flowing at the base of an ice sheet, deposited its sediment load. Surrounding areas are part of the coastal lowlands. Photograph by L.A. Dredge. GSC 2000-012H

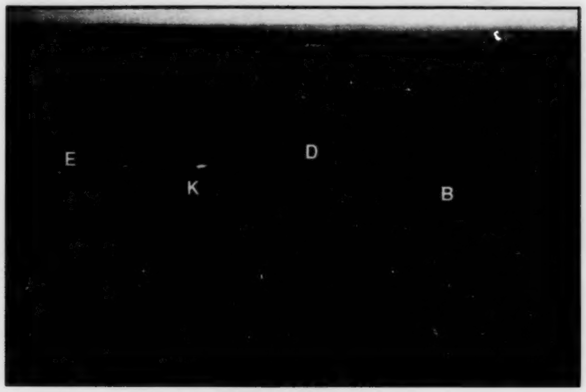


***Figure 23.** Outwash delta and postglacial marine plains east of Bloody Fall. The flat, raised surface in the foreground is an outwash delta (D) that was created where meltwater, issuing from the front of the receding glacier, flowed into a high-level sea. The winding ridge is an esker (E). The small ponds occupy kettle holes (K), depressions where glacial ice that had been buried by the sediments finally melted. A series of beaches (B) developed on the right side of the delta as the sea receded. Photograph by L.A. Dredge. GSC 2000-012I*

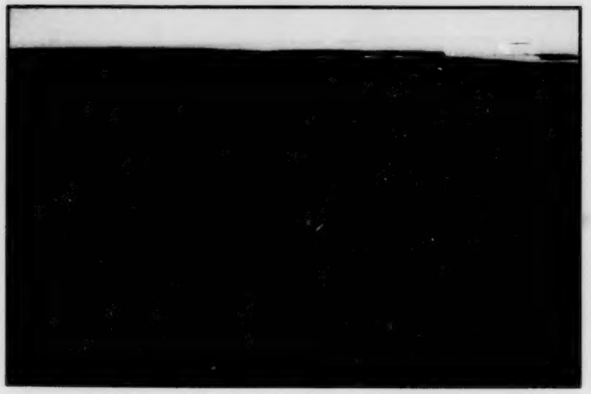


***Figure 24.** A series of sandy raised-beach ridges on the coast near the Kugaryuak River. They rise inland from the coast to an elevation of about 30 m. The linear depressions on the beaches in the foreground are ice-wedge polygons. A cliff, capped by a gabbro sill, can be seen in the distance. Photograph by L.A. Dredge. GSC 2000-012J*

***Figure 25.** Lowlands east of Bloody Fall consist of a layer of surface sand, underlain by postglacial marine silt and clay that are exposed where gullies have eroded back into the coastal-plain sediments. Photograph by L.A. Dredge. GSC 2000-012K*

Large, terraced, delta-shaped deposits, covered with shallow distributary channel scars, expand outward at intervals along the Coppermine River, marking successive positions of the river mouth. The deltas consist of thick wedges of sand and gravel that grade downward into finer marine deposits.

Alluvium occupies corridors that either once were, or are presently, occupied by river beds. In this area, most deposits form terraces along and above the Coppermine River. In most places, alluvium consists of sand or gravel sorted and stratified by the river. Above Bloody Fall, however, some of the alluvium, particularly shoals in the modern river bed, is fine grained because of redeposition of material from the clay cliffs that form the banks of the river. In general, old alluvial deposits are good sources of coarse aggregate, and buried alluvium can be a good aquifer and source of groundwater where the deposits are unfrozen.

Circular ponds and linear ice-wedge depressions shown on the detailed map (Fig. 18) are common on the plains west of Kugluktuk. These features have resulted from the thawing of ground ice in the raised marine deposits, and subsequent subsidence of the land surface.

Ice-age events

All the land around Kugluktuk, except the rock knobs, has been formed by glacial and postglacial events. In western Canada, ice from the Keewatin Centre covered Coronation Gulf and extended as far west as Paulatuk and Banks Island about 18 000 to 25 000 years ago (Fig. 14). Another long prong of ice flowed northward from the main ice mass down the Mackenzie River valley. Near Kugluktuk, the glacier flowed north and northwest. Sharp rock fragments were dragged along the base of the glacier and produced striations (scratches) on bedrock surfaces. These are visible on some of the rock knobs at Kugluktuk. The orientation of drumlins on the till surfaces inland confirms that the glacier flowed toward the north and northwest in this area.

By 13 000 years ago, the ice sheet had begun to melt. The ice margin receded toward the east and the ice sheet became thinner. As ice flow became more influenced by topographic features, glacial lobes began to flow preferentially through lowland terrain, especially along Coronation Gulf. This ice flow is recorded by westward-trending striations on the islands of Coronation Gulf and the nearby mainland. These striations are superimposed on the older northwesterly set and, in fact, are the most common striations on rocks around Kugluktuk.

About 11 000 years ago, the land west of Coppermine River became free of ice, although a lobe of ice was still present in the lowlands of Coronation Gulf (Fig. 26A). This ice lobe acted as a dam that prevented meltwater issuing from other parts of the ice margin from reaching the sea. As a result, a glacial lake, called glacial Lake Coppermine, formed between the main continental ice margin and the Coronation ice lobe. It extended along the Coppermine River valley south of this area, from Rocky Defile Rapids as far as Fairy Lake River (St-Onge, 1980). This lake lasted until the Coronation lobe retreated farther eastward, at which time the meltwater was free to drain into the ocean.

By 10 000 years ago, ice was gone from Coronation Gulf and the only glacier margin lay on the uplands about 20 km inland (Fig. 26B). The ice front was oriented east-west. Striations, long drumlins, and esker segments indicate that the main direction of ice flow at this time was to the north, toward the receding ice margin. After this time, the ice margin continued to shrink back to a final position west of Rankin Inlet on the northwest shore of Hudson Bay, where the last traces disappeared about 6500 years ago.

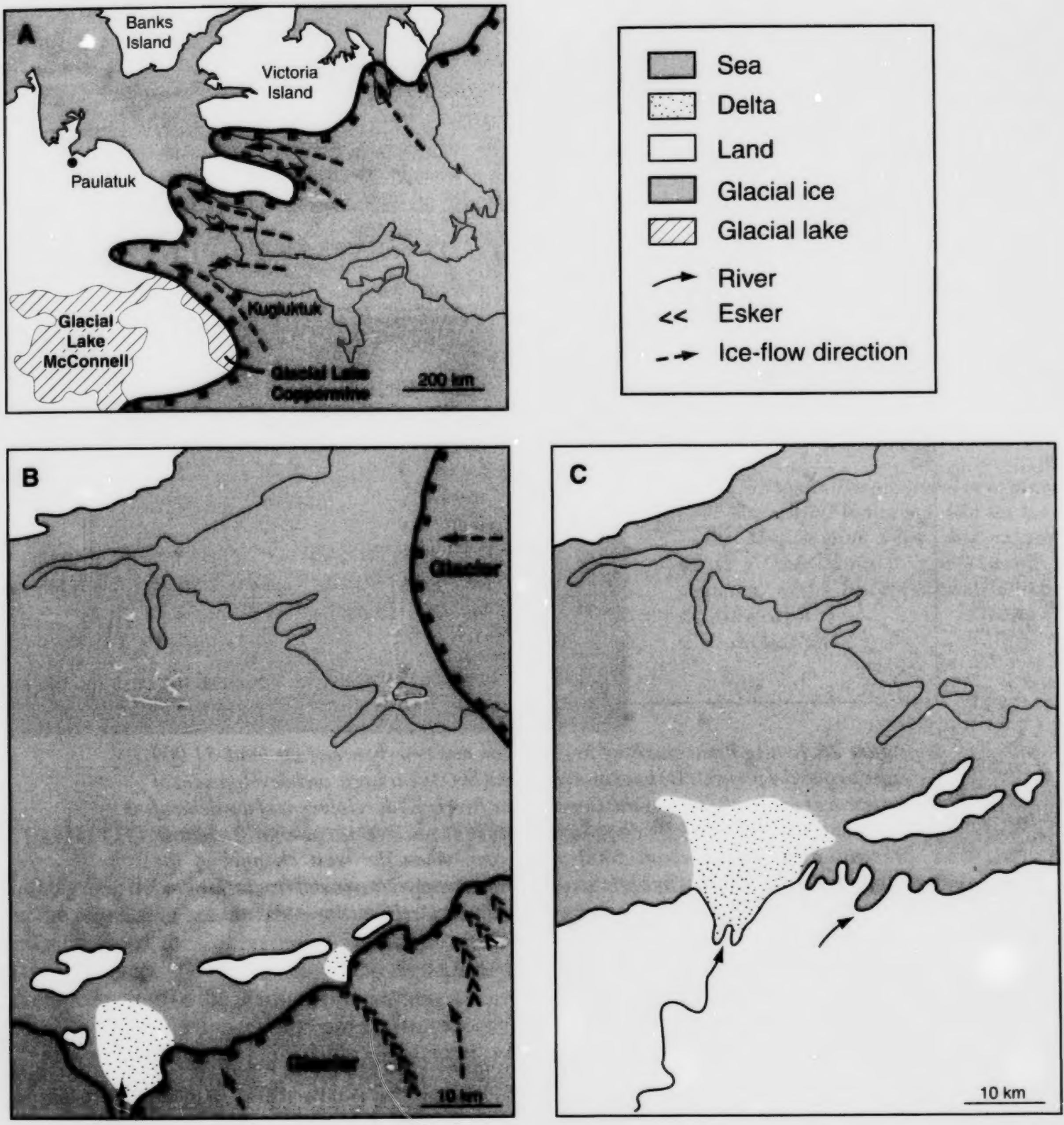

A
Banks Island
Victoria Island
Paulatuk
Glacial Lake McConnell
Kugluktuk
Glacial Lake Coppermine
200 km
Sea
Delta
Land
Glacial ice
Glacial lake
River
Esker
Ice-flow direction
B
Glacier
Glacier
10 km
C
10 km

Figure 26. *Final stages of deglaciation and emergence of the land, 11 000 years ago to the present:* ***A)*** *glaciers and glacial lakes in the western Arctic, 11 000 years ago (*from *Dyke and Prest, 1987);* ***B)*** *retreat of the Coronation ice lobe and the mainland glacier about 10 500 years ago, when sea level was about 160 m higher than at present;* ***C)*** *development of deltas near Bloody Fall about 9000 years ago; some areas above 100 m elevation were islands in the postglacial sea.*

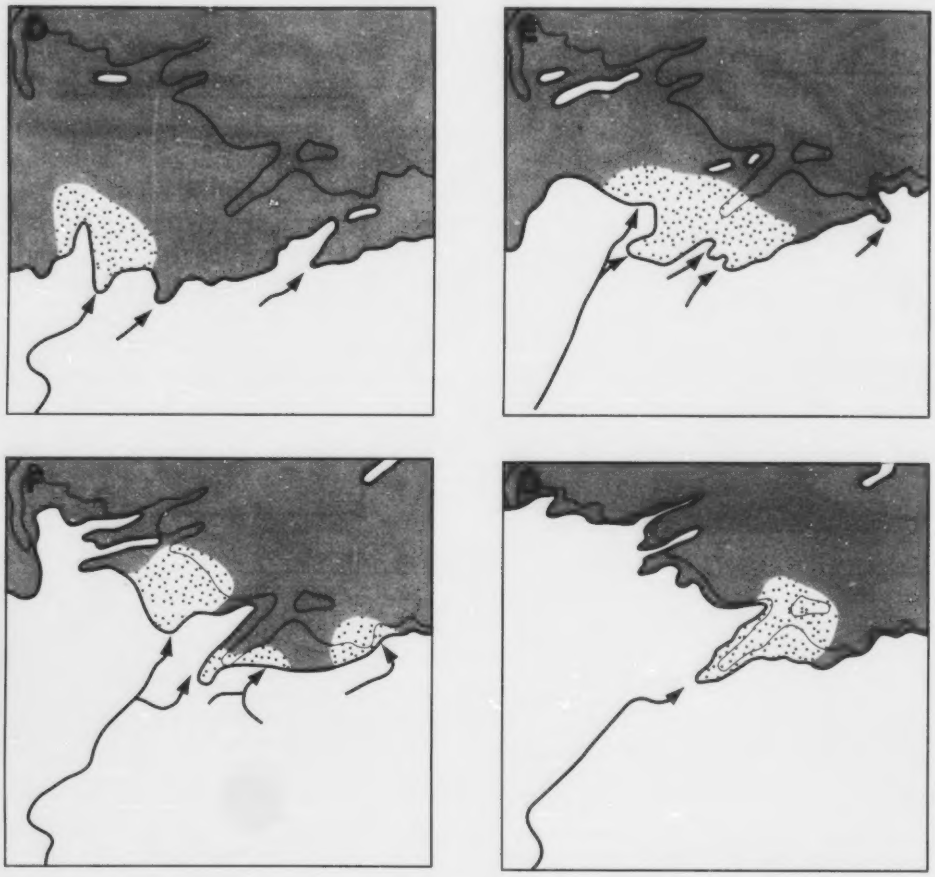


Figure 26. *(cont.) Final stages of deglaciation and emergence of the land, 11 000 years ago to the present:* ***D)*** *land and sea about 8000 years ago, and development of the terraces at 70–80 m along the Coppermine River;* ***E)*** *development of the delta of 6000 years ago, and emergence of Saddleback hill; sea level was about 30 m above present;* ***F)*** *coastline about 5000 years ago, when the west channel of the Coppermine River was active and sea level was about 20 m above present;* ***G)*** *land and sea about 3500 years ago, when sea level was 10–15 m above present.*

Postglacial marine events

Due to isostatic depression of the Earth's crust, the sea followed the retreating ice sheet southward. Along the open coast, it extended about 20 km inland and reached a limit that is now 160–170 m above present sea level. In the Coppermine River valley, it penetrated even farther, to Muskox Rapids, which is about 50 km from the coast (*see* Fig. 1). This high postglacial sea has since regressed to its present position, leaving exposed the old marine sediments. Fine-grained sediments, deposited in deep water away from currents, were reworked and overlain by shallow-water sand and gravel deposits during the regression. Successive positions of the coast are marked by beach ridges and by a series of deltas deposited where meltwater streams and rivers entered the sea.

Postglacial marine fossils

The most common marine fossils found in the Coppermine area are shown in Figure 27. Fossil marine molluscs, looking much like present-day species, lived in the seas that covered the Kugluktuk area after the ice ages. These fossils can be seen in the old marine clay deposits exposed along the bluffs that form the banks of the Coppermine River. The types of fossils found give us information about the salinity and temperature of the waters in which they lived. Those collected from this area indicate cold-water, marine environments. Some shells have been radiocarbon dated. The oldest shells from the Coppermine River, collected above Bloody Fall at an elevation of 100 m, were dated at 9800 ± 90 years before present (St-Onge, 1987, GSC-3327).

Figure 27.

Fossil sea shells that are found in western Coronation Gulf look much like modern shells. Shown, from top to bottom, are pairs of Macoma brota, Macoma calcarea, *and* Clinocardium ciliatum. *Photograph by L.A. Dredge. GSC 2000-012M*

Evolution of the lower Coppermine River

The stages in the evolution of the lower Coppermine River, and the relationships between the emerging land and the regressing sea, are shown by a series of diagrams that cover the postglacial period (Fig 26). As the land rebounded, the Coppermine River cut down through the layers of old marine sediments, exposing them in the cliff faces above and below Bloody Fall. Large deltas, with distributary channels on their surfaces, developed on top of the marine beds, forming a downstepped series of terraces along the Coppermine River (Fig. 28). The main upper deltas are at elevations of 160–170 m (Muskox Rapids), 105 m (Escape Rapids), 100 m (south of Bloody Fall), 80 m (north of Bloody Fall), 30 m, 20 m, 10 m, and the present delta. The course of the river was not always along the present waterway. About 5000 years ago, when sea level was about 20 m above present, the main river channel lay 6 km west of the present channel. Since then, low alluvial terraces have been cut or deposited above the present river channel, indicating a course similar to the present one.

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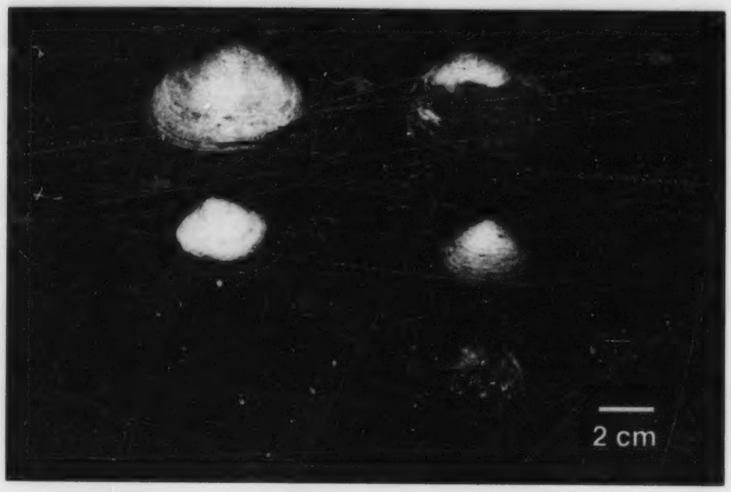

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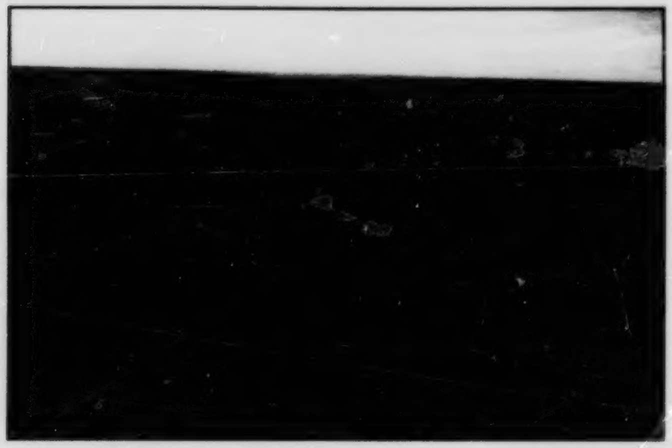


Figure 28.

Ancient terraces and channels formed by the Coppermine River, with the modern river incised into the old terraces. The terraces shown here range in elevation from 30 m (lower right) up to 90 m above sea level. Photograph by L.A. Dredge.
GSC 2000-012N

Climate change in the last 10 000 years

Past climate

The climate in the Coppermine area has not always been like the present. From the study of the pollen record in peat deposits near the community, one near Saddleback hill and the other near the airport, a botanist named Harvey Nichols (1975) reconstructed climatic conditions over the last 4000 years. He looked first at pollen grains at a series of depths in the peat; from these observations, he reconstructed the vegetation that grew in the area as each peat layer accumulated. He then interpreted the sequence of vegetation changes in terms of climate change. Marker dates were obtained by radiocarbon dating of layers of the peat.

The record of climatic change near Coppermine is summarized in the graph in Figure 29. Radiocarbon dates on twigs from peat bogs and glacial sediments farther inland show that vegetation was established in the upper Coppermine valley by about 9100 years ago, and that the climate was cold at that time. By about 7500 years ago, however, when Saddleback hill was emerging from the sea, the climate was warmer than present, possibly by 3°C. Treeline on the uplands may have extended as far north as Bloody Fall at this time. The woodlands at Escape Rapids may be isolated descendants of the forest of 7000 years ago. By about 6500 years ago, the climate had begun to turn cold, and the treeline subsequently migrated even farther south than its present position. Between 3700 and 3200 years ago, the climate warmed, so that birch and Potentilla shrubs extended almost to the coast. Another cold period

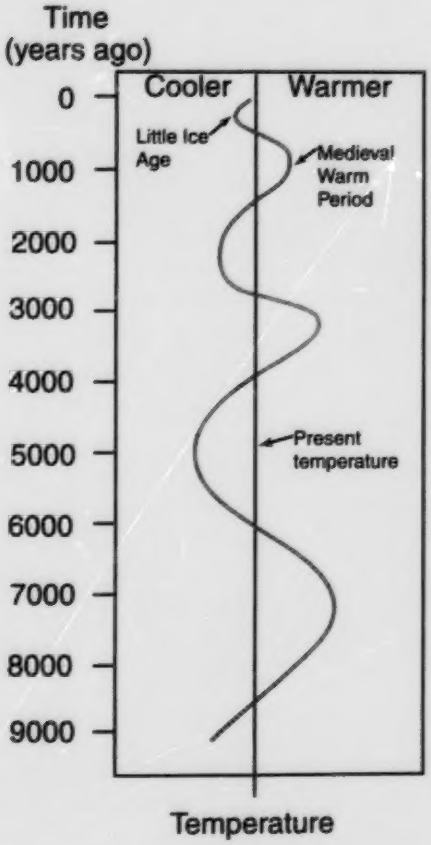


***Figure 29.** Climate change at Coppermine, as reflected in the record of changing vegetation (after Nichols, 1975).*

followed, recognized in the peat record as a period of slower peat growth and fewer dwarf birch pollen, and lasted until about 1000 years ago. There was probably also more sea ice during this period. Between 1000 and 750 years ago, a time known as the Medieval Warm Period, the climate became slightly warmer than present, both here and worldwide. Tree species extended northward of their present limit, and willows and grass proliferated at Kugluktuk. The Little Ice Age, lasting between 750 and 150 years ago, is characterized at Kugluktuk by a decline in wind-transported tree pollen, fewer birch, and more sphagnum (peat), sedge, and heath pollen, all indicating a cooler, drier climate. The last 150 years have been characterized by a warming trend and a climate similar to the present.

Weather records show that mean annual air temperatures inland from Kugluktuk have increased by 1.7°C in the last hundred years, although increases along the coast may have been closer to 1°C. This warming trend may reflect natural variability, and a recovery from the Little Ice Age, or the effects of man on global land use with the production of greenhouse gases.

Future trends

The effect of global warming, particularly from an increase in carbon dioxide and related 'greenhouse gases', has recently become an issue of world concern. There are some indications that the amount of greenhouse gases could double in the first half of the next century. Models for the Arctic predict a corresponding annual temperature increase of about 5°C. The mean annual air temperature at Kugluktuk at the end of the next century might be about -7°C (compared with -12° at present). This corresponds to temperatures presently experienced near Inuvik, or to boreal areas about 400 km farther south. It is interesting that this is the same amount of warming experienced in the warmest periods between major ice ages.

PART III: THE PRESENT LANDSCAPE

Kugluktuk is situated in an active geomorphic environment. The land continues to rise at a rate of 20–50 cm per century; winds and waves modify the coast; streams are cutting through the glacial and raised marine deposits; the river continues to bring sediment down to the delta, contributing to its growth; gullying along the Coppermine River contributes sediment that forms river bars and shoals, and may have temporarily blocked the flow of the river at times; ground ice aggrades or thaws in the subsoil on the coastal plain; ponds drain; bedrock surfaces break up by frost-heave processes; and broken-off rock blocks continue to tumble from the bedrock cliffs. Who said that nothing happens in Kugluktuk?

Permafrost

Permafrost is defined on the basis of temperature, as soil or rock that remains below 0°C year-round. It develops where the ground cools sufficiently in winter that it does not warm above freezing, even in summer. However, even in permafrost areas, a thin surface layer of ground thaws each year in summer. This layer, which freezes and thaws with the seasons, is called the 'active layer'.

Most of Nunavut is underlain by permafrost. The presence or absence of permafrost determines which plants and animals can survive on the land. It also determines how human beings build homes, roadways, and other facilities, all of which must be specially designed for permafrost conditions.

Distribution

Permafrost underlies more than 50% of the Canadian landmass (Fig. 30). It is commonly divided into three categories based on its areal extent. In the continuous permafrost zone, permafrost underlies all, or almost all, the area. It is in this zone that permafrost is thickest, up to 500 m on some Arctic islands. To the south, in the discontinuous zone, permafrost underlies 30–50% of the area. Large lakes commonly have no permafrost beneath them and, where there is permafrost, it is usually much thinner than in the continuous zone. In the sporadic zone, permafrost underlies less than 30% of the area and is generally thin. It often persists where peat shields the ground from summer heat.

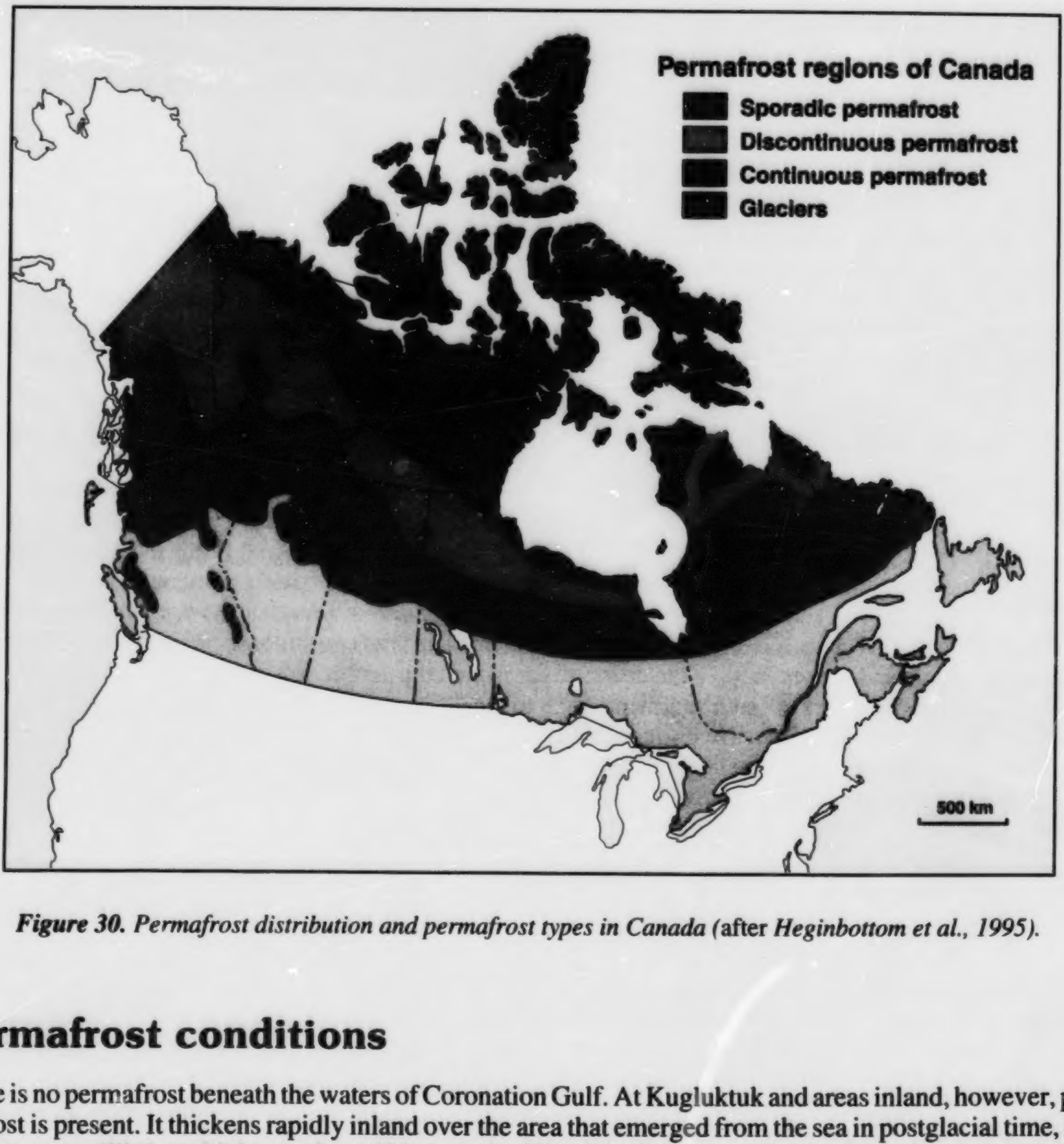


Figure 30. Permafrost distribution and permafrost types in Canada (after *Heginbottom et al., 1995).*

Permafrost conditions

There is no permafrost beneath the waters of Coronation Gulf. At Kugluktuk and areas inland, however, permafrost is present. It thickens rapidly inland over the area that emerged from the sea in postglacial time, and reaches an equilibrium thickness about 25 km south of Kugluktuk, in areas that lie above the postglacial sea (Fig. 31).

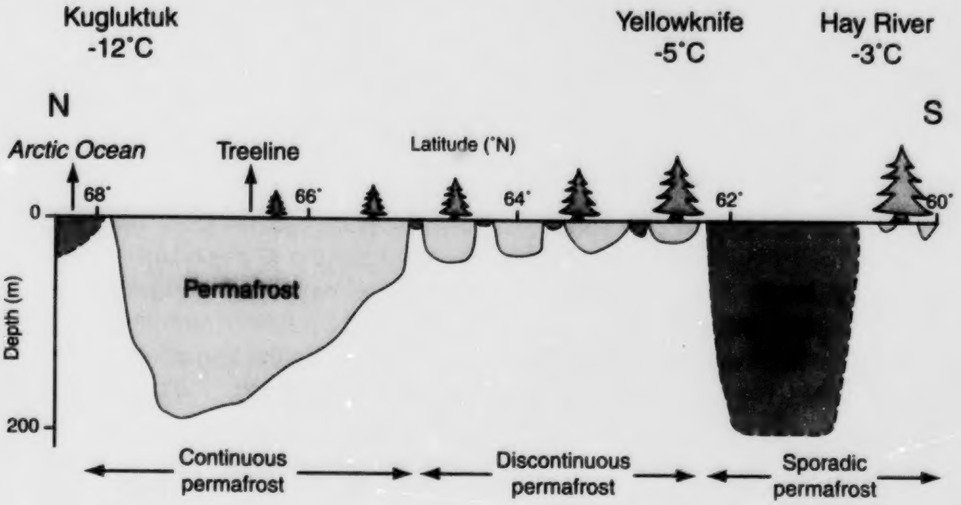

Kugluktuk
-12°C
Yellowknife
-5°C
Hay River
-3°C
N
S
Arctic Ocean
Treeline
Latitude (°N)
68°
66°
64°
62°
60°
0
200
Depth (m)
Permafrost
Continuous permafrost
Discontinuous permafrost
Sporadic permafrost

Figure 31. Thickness of permafrost along a north-south transect from Kugluktuk (modified from *Wolfe, 1998).*

A deep borehole in the September Mountains, 50 km south of Kugluktuk, shows that the permafrost is about 160 m thick. Below that depth, the Earth's heat (geothermal heat) keeps temperatures above freezing.

Ground-temperature data were collected from sites about 15 km east of Kugluktuk in 1995 and 1996 (Wolfe, 2000). The terrain at these sites is similar to that of the coastal plain near the hamlet, so the thermal regime is probably similar. Temperature cables were installed in holes drilled through a sod mat, a sand layer about 2 m thick, and into thick deposits of silt. The temperature graph (Fig. 32) shows that, below a depth of about 5 m, the ground temperature is steady at about -7°C, or 5°C warmer than the mean air temperature. Temperatures just below the ground surface fluctuate seasonally, and range from about 5°C in July to -15°C in February. In contrast, air temperatures varied from 14°C to -27°C over the same period. The vegetation mat is clearly a good heat insulator. Active-layer thickness at the site shown on the graph is the depth at which the temperature curve crosses the 0°C line. In this case, the active layer is about 1 m thick.

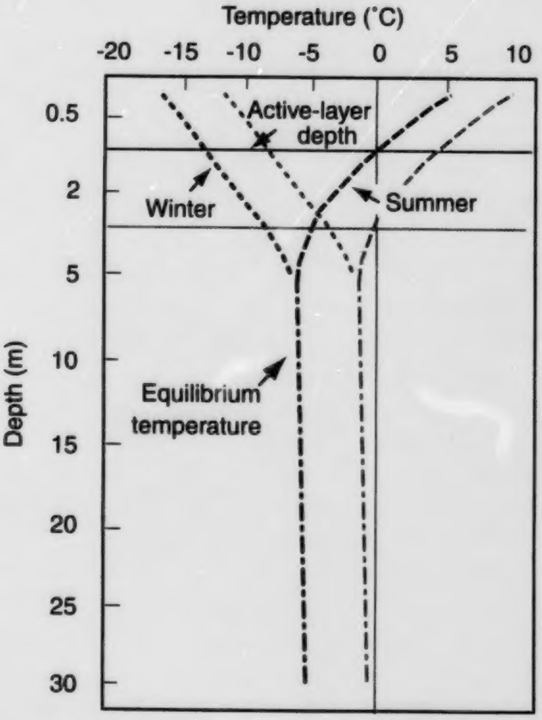


Figure 32. Near-surface ground temperatures from a site 15 km east of Kugluktuk (Wolfe, 2000). Possible ground temperatures associated with climate warming due to doubling of greenhouse gases are shown in blue.

Lakes that are more than 4 m deep usually do not freeze to the bottom in winter. Those studied on the coastal plain were 3–4 m deep, with bottoms of sand and old marine silt. The mean bottom temperature was 4°C, but temperatures reached as high as 17° in summer, and as low as 1°C in winter.

What affects permafrost?

Air and water temperatures

On a national scale, permafrost conditions depend on regional air temperatures. Areas of continuous permafrost occur where mean annual air temperatures are less than -8°C, and discontinuous permafrost is prevalent where air temperatures average between -1°C and -8°C. Water bodies also affect permafrost conditions: as mentioned previously, there is no permafrost below major water bodies such as Coronation Gulf.

Permafrost conditions, and particularly the depth of the active layer, are also highly dependent on vegetation cover, soil types, and moisture conditions.

Turf mats and peat

Turf refers to the continuous decomposed vegetation mat overlying rock and soil. Peat is the dense form of turf that accumulates in wetland conditions and consists mainly of decomposed moss or sedge. The turf mat is generally thin on the Arctic mainland, but some peat deposits are more than 5 m thick. Turf and peat mats act as a form of insulation. Dry turf has a low thermal conductivity. In other words, it prevents heat energy from passing through it. Dry turf therefore restricts the flow of heat from the air into the subsoil in summer, preventing thawing that would otherwise occur. In contrast, wet turf and peat, or frozen peat containing ice, have high thermal conductivities and therefore transmit heat out of the ground and into the air in fall and winter. Because of these unique properties of turf mats, vegetation cover can have a profound effect on permafrost conditions.

As the thickness of the turf layer increases, the depth of the active layer decreases systematically. A good example of this was seen in small pits dug in late July on the raised beaches between the airport and the shore. Sites directly behind the modern beach, which were not yet fully colonized by vegetation, had an active layer depth of 87 cm. Farther inland, where the turf was 3–5 cm thick, the active layer depth was 60 cm. On the oldest beaches, where vegetation was well established and the turf was about 12 cm deep, the active layer was only 26 cm. In all cases, the underlying sand layer was frozen hard but contained only small amounts of ice in the spaces between sand grains.

Disturbing the vegetation can have a dramatic effect on freezing or thawing of the soil, particularly if the soil contains ice. This is because removing the vegetation, or changing its insulating properties, will also change the active-layer depth. For instance, the all-terrain vehicle (ATV) trail to Bloody Fall crosses many ice-wedge troughs. Away from the trail, these troughs are roughly 40 cm deep. Where ATVs have passed often, however, the vegetation cover has been removed or compacted, so that its insulating properties have changed. As a result, the active layer has deepened. The upper layer of perennial ice beneath the troughs has melted, causing a subsidence or deepening of the troughs, which in some places are almost a metre deep on the trail.

Soil type and soil-particle size

Different types of materials react in different ways to permafrost conditions. For instance, sandy materials, such as those forming the raised beaches and the top layers of the postglacial deltas near Kugluktuk (Fig. 33), freeze at 0°C. Because of their porous nature (there are large air spaces between grains), liquid water migrates easily through the sand deposits when they are thawed (i.e. they are well drained). The sand deposits are generally stable when frozen, although there are exceptions. When water freezes in sandy materials, ice crystals occupy some of the pores or air spaces between sand grains, but if the sand is well drained, ice rarely forms outside the pores. One exception to this is ice wedges, which develop by another process in the upper parts of sand bodies. Another exception occurs where drainage of water in the lower part of a sand body is blocked by nonporous material, such as bedrock, clay, or frozen sand in which all the pores are already filled with ice.

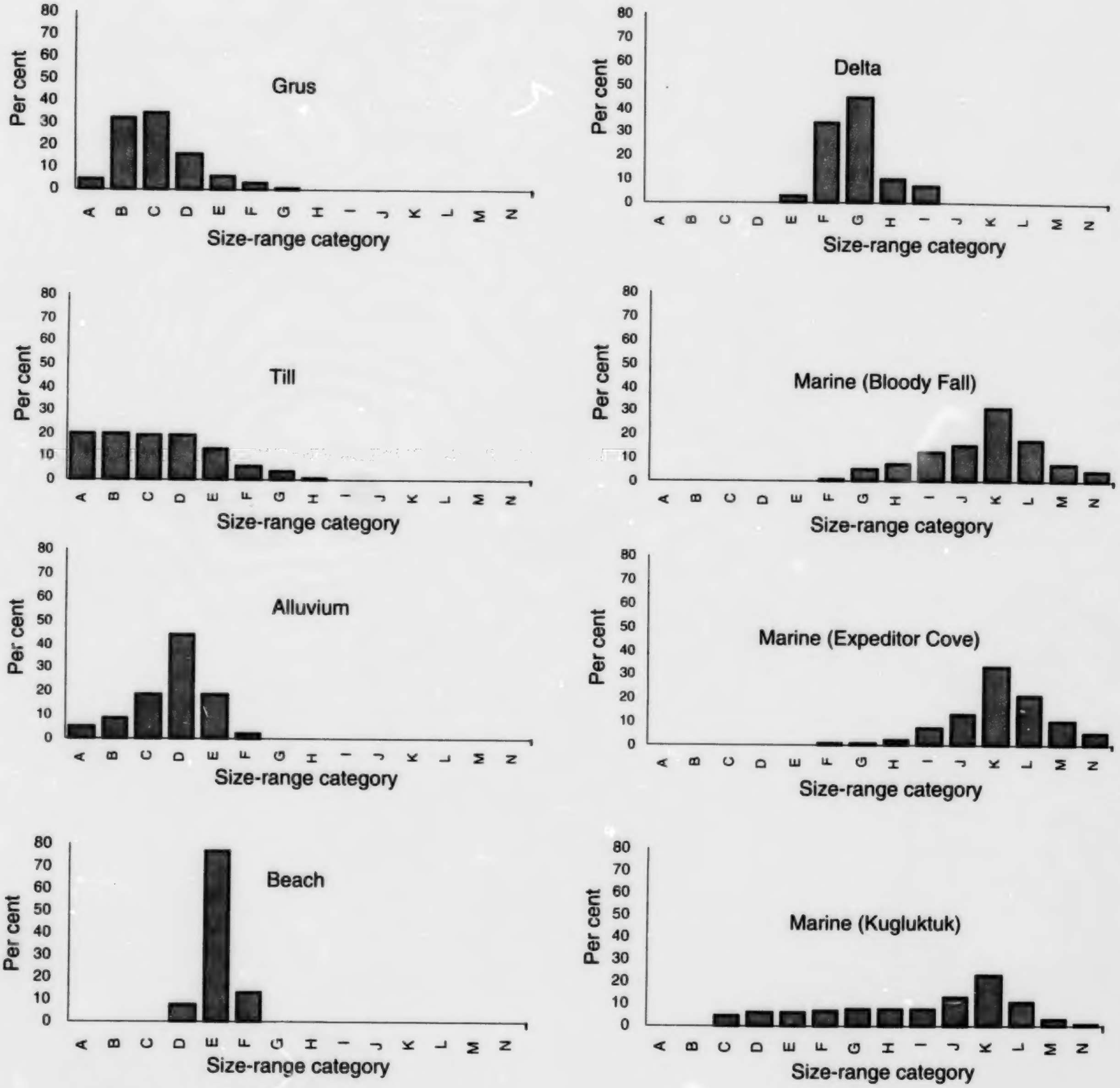
Pure clay (particles less than 0.002 mm in diameter) reacts differently. First, it tends to freeze at a temperature below 0°C due to subatomic forces acting between water molecules and clay-sized particles. In other words, when water is beginning to turn into ice in the sand bodies, it is still unfrozen in the underlying clay deposits. Also, water does not drain through clay easily (i.e. it has low permeability), but water contents can be very high because of the forces binding water to the edges of clay particles. Dry clay is relatively stable, but wet clay generally behaves as a plastic substance that may have a low yield strength and may flow if a weight is applied to it (e.g. standing on it, building on it, or eroding a clay-sided river bank). Clay that settled into deep quiet waters of the postglacial sea in areas that have since emerged underlies the coastal plain at depth near Kugluktuk. Some of this old marine clay is also exposed along the banks of the Coppermine River, and old glacial-lake clay is exposed farther upstream. Sometimes, particularly during autumn freeze-up, the overlying sand will be frozen, but the clay will still be unfrozen. Unfrozen clay can be squeezed up into any frost cracks in the base of the sand or adjacent rock at this time. If the water content is high, clay slopes may also fail as flowslides.

Silty deposits are those with grain sizes between 0.002 mm and 0.063 mm. Much of the fine grey material underlying the sand on the coastal plain is silt; also, many of the glaciolacustrine deposits of glacial Lake Coppermine are silty. Water can flow slowly through these deposits, but at a rate much less than that at which it flows through sand. Silt tends to have high water or ice content and thus be unstable, particularly following rainfall or during the spring melt. Silt deposited in a marine environment, such as those units underlying the coastal plain, can be especially unstable because pore spaces (and therefore the amount of water the silt can hold) are especially large. Such silty soils are highly frost susceptible. Another characteristic of silt is that water will migrate to patches of it that are frozen, and then freeze onto the frozen patches. This means that ice layers and lenses, some up to several metres thick, can form in silt.

Moisture (ground ice)

Although permafrost is strictly defined as a temperature condition, it is the ice content in the ground that is the most important aspect affecting earth-surface processes and engineered structures. 'Ground ice' refers to all types of ice formed in frozen ground. As indicated in the previous section, material type influences the amount and type of ground ice because of differences in the way that water migrates through them and the total amount of water they can hold. Ground ice occupies fissures in rock, and pore spaces and fissures in sediments. It can form coatings around grains, fill or partially fill pore spaces between particles, or form wedges (Fig. 34) or lenses of pure, massive ice.

As water freezes, it expands by 9% of its volume. In fissured rock or sand deposits where water contents are low, the expanded ice simply occupies more of the available air spaces, so that the material is still stable. In water-filled rock fissures, saturated sand, and finer grained materials that are slow to drain and generally



Size-range categories:

A, Pebbles (8–4 mm)
B, Granules (4–2 mm)
C–G, Sand (2–0.063 mm)
H–L, Silt (0.063–0.002 mm)
M–N, Clay (<0.002 mm)

Figure 33. *Grain-size ranges for various surface materials near Kugluktuk.*

Figure 34.

Upper part of a carrot-shaped wedge of massive ice extending about 3 m into sandy sediment. Note that the wedge starts about 1 m below the surface due to thawing at the top. The notebook, used for scale, is 20 cm long. Photograph by L.A. Dredge. GSC 2000-012O

have high initial water contents, the expansion of water as it freezes causes unstable conditions. As water freezes and expands, heaving or doming occurs. This is especially noticeable on bedrock surfaces where water could not drain out before freezing (from the surface down), but also occurs in peat deposits, in silt units, and along ice wedges in sand. Repeated cycles of frost heave can occur, resulting in frost jacking. It is this process that results in the heaving of massive rock blocks seen on outcrops near Kugluktuk.

When materials thaw and ice in the active layer melts, subsidence occurs. In silty soils, thawing also commonly leads to saturation of the soil, because the silt tends to contain massive, segregated ice lenses. Slope failures are then common in these materials, producing active-layer detachment slides, flowslides along riverbanks, and solifluction lobes. Repeated heave and subsidence can wreak havoc with buildings and roads if they are not properly designed.

Home improvements

Steps can be taken to minimize the effects of heaving and subsidence, mainly by stabilizing conditions within the active layer. One way is to minimize disturbance by not removing vegetation cover. Making sure that areas have good drainage is a second way. On building sites, putting a thick pad of permeable gravel on the ground ensures that water can drain out before freeze-up (Fig. 35). If the pad is made thicker than the depth of the active layer, then a new active layer will stabilize within the well drained pad over time, thereby maintaining stable sub-zero temperatures in the frost-susceptible materials beneath. Another method is to insulate structures so that heat from them does not penetrate into the ground and deepen the active layer. This can be done either by placing a layer of insulation between the structure and the ground, or by leaving a space for air circulation between the base of the structure and the ground by raising it on pylons. Thermosyphons, pipes filled with carbon dioxide, are a new device for maintaining stability around structures by extracting heat from the ground. They have been used successfully in Yellowknife to prevent subsidence of buildings, and at the Lac de Gras diamond mines to maintain the integrity of dams (Fig. 36).

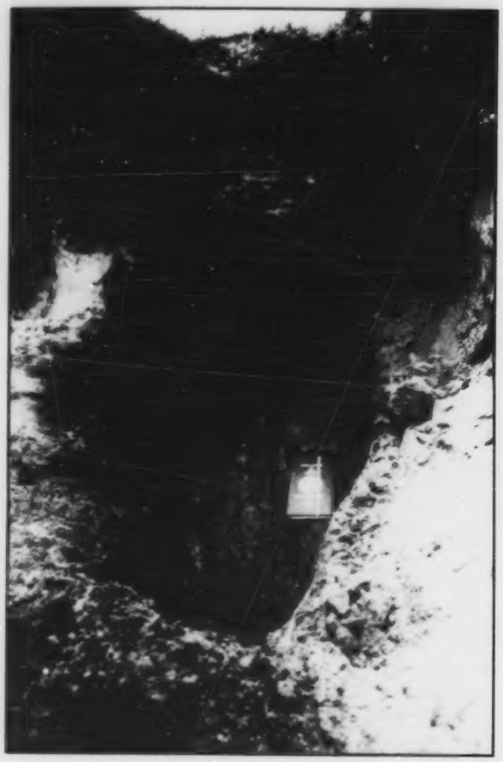


Figure 34.

Upper part of a carrot-shaped wedge of massive ice extending about 3 m into sandy sediment. Note that the wedge starts about 1 m below the surface due to thawing at the top. The notebook, used for scale, is 20 cm long. Photograph by L.A. Dredge. GSC 2000-012O

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Figure 35. *This house has two features that help maintain thermal equilibrium in the ground: a thick gravel pad, and an air space between the floor and the ground surface. Photograph by L.A. Dredge. GSC 2000-012P*

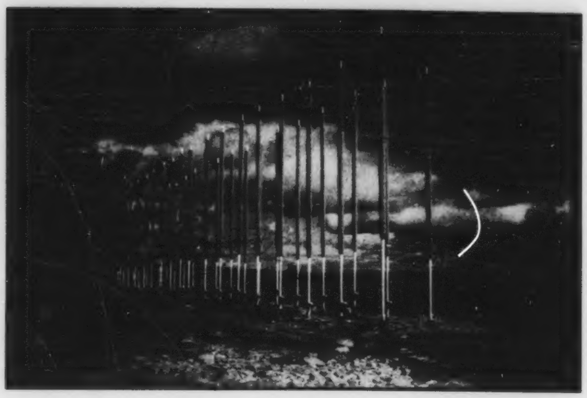


Figure 36. *Thermosyphons are sealed columns filled with carbon dioxide that help maintain sub-zero temperatures in the ground. This photo shows a dam constructed at the Ekati diamond mine near Lac de Gras. Note people in lower left for scale. Photograph by L.A. Dredge. GSC 2000-012Q*

Landforms related to permafrost conditions

Rock, glacial, and postglacial landforms have been modified by the present periglacial climate (a climate in which frost action is an important factor). Many periglacial landforms were produced by processes operating in the active layer, the upper zone of rock/sediment that freezes and thaws seasonally. Most landforms associated with permafrost are related to the growth or thawing of ground ice in rock and sediments. As ground ice develops, the expansion of water in rock and soil as it freezes leads to heaving and shattering of bedrock, and doming of soil and peat. As ice bodies in the ground thaw, subsidence occurs.

Rock jumbles are piles of frost-shattered rock that have been heaved up and split open by frost action. As water freezes in cracks in the rock, it expands in volume by 9%, causing the rock to react either by heaving upward (the path of least resistance) or by splitting apart. Rock jumbles are common on the sills near Kugluktuk, and protrude above the otherwise smoothly glaciated rock surfaces. They develop preferentially where water has accumulated in small depressions in the rock (Fig. 37; *see* Part IV, Stop 11).

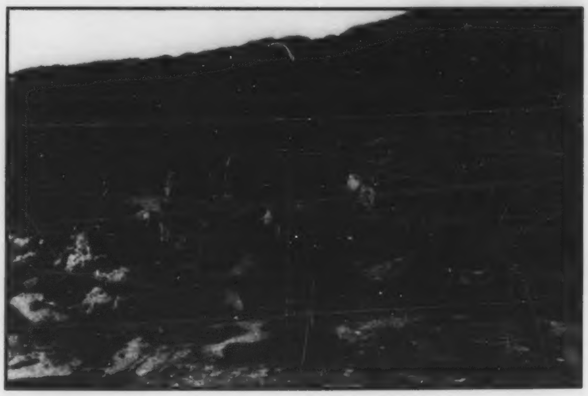


Figure 37. *Jumble of angular rock blocks caused by frost heave and shattering of bedrock. Hammer in lower left corner is 35 cm long. Photograph by L.A. Dredge. GSC 2000-012R*

Rock panels are large blocks of frost-shattered rock whose edges are natural joints. Panels have been frost-heaved up to 3 m above the glaciated rock surface. Hydraulic pressure is another agent responsible for heaving of the panels. It acts when there are water-filled cracks around the rock block. In the fall, water in cracks freezes from the top down; as it freezes, it expands and puts pressure on the unfrozen water below. The unfrozen, pressurized water can put a heaving pressure of up to 400 kPa on the rock, causing the block to rise (the only direction it can go). If grit or small pebbles drop into the cracks after the block has been heaved up, or if ice forms in the cavity below the uplifted block, it cannot fall back down into its socket the following summer (Fig. 38; *see* Part IV, Stop 11).

Rock polygons are reticulated (rectangular) features of frost-shattered rock. They are created along rectangular networks of fissures or joints in relatively weak sedimentary rocks when water freezes in cracks, and then bends, buckles, or thrusts up the overlying strata. If the thrusting force is great enough, the rock will break, forming networks of upraised slabs. These features are common on the limestone surfaces north of the Rae River and west of Richardson Bay. Rock blisters are circular mounds of upheaved rock formed in a similar manner (*see* Part IV, Stop 39).

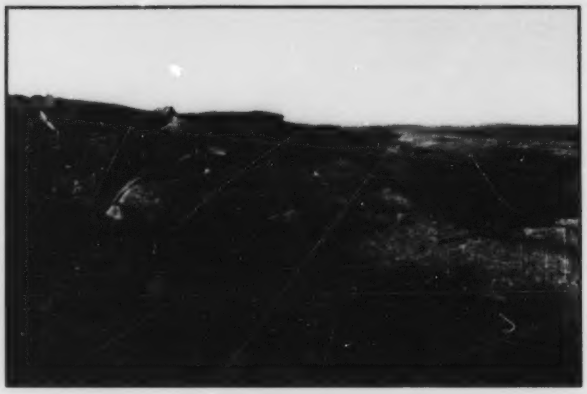
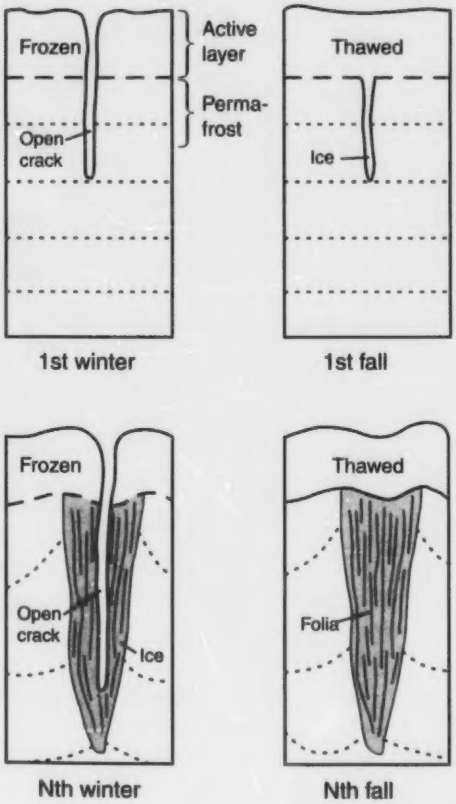


Figure 38. *Panels of jointed rock have been repeatedly frost heaved above adjacent bedrock surfaces, but have otherwise remained intact. The upper, glacially polished or scratched surface is preserved. Note bushes in lower left for scale. Photograph by L.A. Dredge. GSC 2000-012S*

Topples, explained previously, are partly periglacial in origin, as frost pressure is commonly one factor in creating widened fissures behind cliffs and in forcing rock slabs outward beyond the cliff face. Once the centre of gravity lies beyond the cliff, the rock mass detaches and falls (*see* Part IV, Stop 13).



Ice wedges are massive, carrot- or wedge-shaped bodies of ice, composed of vertically banded, commonly white ice. They form in sand and gravel in outwash plains and raised beaches, when melting snow penetrates into contraction cracks. Repeated contraction cracking over a period of years increases the width of the wedges and causes vertical layering of the ice mass as each successive water layer freezes on (Fig. 39).

Ice-wedge polygons are rectangular sets of depressions in peat or sand underlain by ice wedges. Good examples are seen on the raised beaches at 4-Mile bay, on the high terraces near Bloody Fall, and south of Heart lake.

Mud boils are small, patterned-ground forms less than a metre across that form 'polka dots' on the ground surface. They generally consist of a fine-grained centre, surrounded by stonier material or by vegetation. They result from repeated seasonal frost-churning of the active layer, which involves lateral thrusting of material, and sinking of grains when the surface crust dries out. These features are common on till plains, on silty soils of the coastal plain, and in low, wet areas such as Snowboard hill in Kugluktuk.

Figure 39. *Stages in the development of an ice wedge* (after *Lachenbruch, 1962).*

Solifluction lobes are shallow, tongue-shaped features that form on slopes because of soil creep downslope. The 'snout' of the lobe is the thickest part. The tail of the lobe thins upslope and gradually merges with stable materials. Downslope creep is particularly active after snowmelt, when soils hold large amounts of water. The weight of the water adds to the gravitational force, pulling material down the slope, and increased pore-water pressure on soil particles reduces the soil's strength.

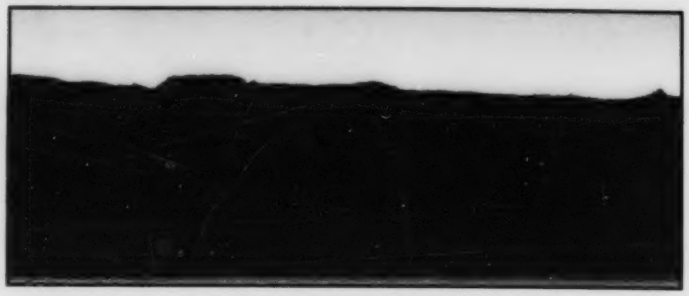


Figure 40. The area of bare silt in the centre of the photo marks the site of a typical, shallow, active-layer detachment failure along the Coppermine River. Area shown in photo is about 10 m wide. Photograph by L.A. Dredge. GSC 2000-012T

Active-layer detachment slides are shallow slope failures of the vegetation mat and underlying active-layer sediments, resulting from detachment of active-layer materials from the underlying frozen material and movement downslope (Fig. 40). Sliding of active-layer sediments occurs when soils are saturated. The weight of water contributes to downslope movement. A layer of water commonly accumulates at the base of the active layer, particularly if the underlying frozen material is poorly drained (i.e. it is fine grained and/or has pore spaces filled with ice). The water layer then acts as a glide plane. Many active-layer detachments have occurred on the coastal plain, where permeable sand that soaks up water is underlain by ice-rich and impermeable clay. Many of the silt/clay areas forming the land surface east of the Coppermine River and the Napaaktoktok River resulted from detachment and downslope movement of the sand, leaving the underlying silt at the surface.

Retrogressive thaw slumps and **thaw flowslides** are common along eroding river banks of silt and clay on the Arctic coastal plain east of Kugluktuk (Fig. 41). They form by slope failure due to thawing of ice-rich permafrost. The slump consists of a headwall that retreats as the permafrost thaws, slices of slumped sediment that have moved downslope, and water-sediment mixtures that have flowed down to the base or toe of the slide to form irregular lumps.

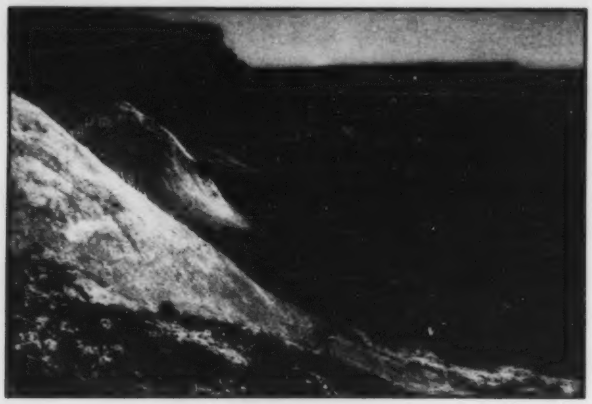


Figure 41. Huge landslides (flowslides) have occurred in silty marine deposits along the Kugaryuak River. A sandy headwall, failed masses of ice-rich silt, and stable pinnacles of undisturbed sediment (foreground) are common along rivers on the coastal plain. Note person in bottom centre of photo for scale. Photograph by L.A. Dredge. GSC 2000-012U

Thaw ponds and **thermokarst lakes** are small water bodies that form where massive ground ice in silty sediments has thawed out, causing subsidence and leaving a surface depression that eventually fills with water. Heat within water molecules in the water body encourages additional thawing, deepening these features and expanding and rounding their sides. The bottoms are generally flat. Numerous thaw lakes, in various stages of development, lie on the sand plains west of Heart lake. Some are more than 4 m deep. Where stream gullies have cut back into the sides of these water-filled depressions and breached the rim, the lakes drain. Draining occurs in stages, depending on the amount of downward erosion. When water starts to drain out, it quickly deepens the stream channel, accelerating the process. The bottoms of drained lakes are now overgrown with shrubby vegetation. (Fig. 42).

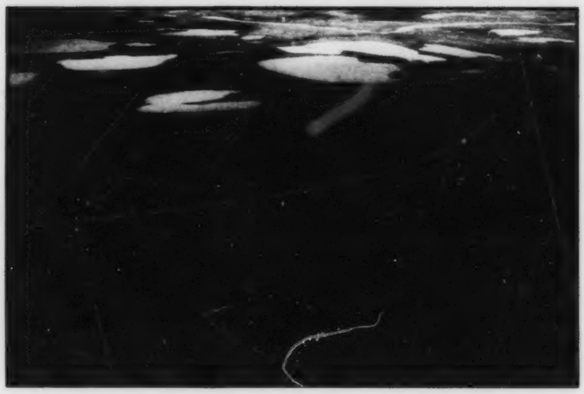


Figure 42. The circular outlines of a drained lake on the coastal lowlands are shown here, as are numerous other shallow thermokarst ponds. Rectangular cracks and patterns in the foreground are ice-wedge polygons. Photograph by L.A. Dredge. GSC 2000-012V

Permafrost and climate change: what if...

It was previously mentioned that the climate has warmed by about 1°C in the past century, and additional rises of about 5°C in air temperature will occur if greenhouse gasses double in the next century.

Mean annual ground temperatures near Kugluktuk are about 5°C warmer than air temperatures. If the expected increase in ground temperature due to doubling of greenhouse gases is similar to that for air temperatures, then the temperature lines on the graph shown in Figure 32 would be shifted about 5° to the right. The average ground temperature would be about -2°C, and near-surface temperatures might range from -10°C in February to 10°C in July. Such a thermal regime would be similar to that of Yellowknife today.

The overall thickness of permafrost would decrease, and permafrost would probably disappear from beneath large lakes. The depth of the active layer would also increase, probably to about 4 m. Many of the lenses of ground ice in fine-grained materials on the coastal plain would melt out, creating numerous thermokarst ponds or depressions. The presence of small water bodies would further deepen the active layer beneath them, degrading more permafrost. There might also be a period with increased frequency of landslides and sediment input along the thawing banks of the Coppermine River. Near-surface ground temperatures would cross and recross the freezing point more frequently than at present, increasing the number of frost-heave cycles. One final effect of global warming is an expected rise in sea level following melting of Arctic and Antarctic glaciers. At Kugluktuk, the present rate of emergence of the land will just about compensate for the sea level rise, so that the coast line should remain about the same.

The modern river and delta

River regimes

The early evolution of the Coppermine River, including major shifts in the position of the delta, was covered in the 'Ice-age legacy' section. Above Bloody Fall, the present river flows through glacial sediments and rock. Where the river has cut through till (unsorted glacial debris), it forms broad channels flanked by gentle valley sides, although there are rapids in some places; between Fairy Lake River and September Mountains, where the river flows through the deposits of glacial Lake Coppermine, the walls tend to be steeper and flank a broad river channel. In places, the river has cut entirely through the glacial deposits and into the bedrock beneath. Where this has happened, the channel is generally narrow and forms a gorge. Rapids are common in these reaches (Fig. 43).

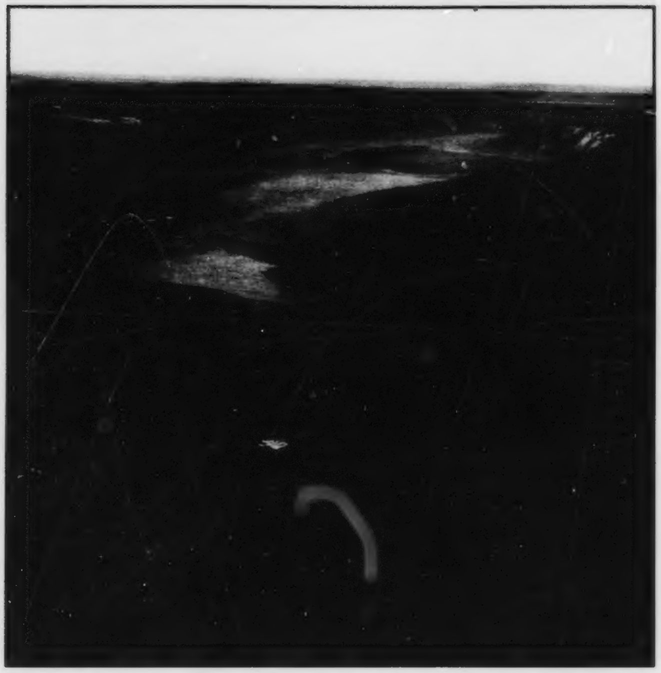


Figure 43. Coppermine River at Escape Rapids, looking north. In the foreground, the river has cut through gabbroic and sedimentary bedrock. Rapids are common in such bedrock areas. In the distance, where the channel is broader, the river has cut through postglacial deposits. Sandy shoals and point bars occupy parts of the channel. Photograph by L.A. Dredge. GSC 2000-012W

At Bloody Fall, flow is fast and turbulent through a narrow gorge where the river cuts through a bedrock sill. The river falls about 10 m, cascading through a set of rapids and chutes. Downstream, below boulder rapids, the river widens and flows more slowly and regularly. The river has cut a series of terraces into the postglacial delta sediments. These terraces form a set of progressively lower benches between Bloody Fall and the coast. It empties into Coronation Gulf on the east side of Kugluktuk.

Near the hamlet, the current slows further as the river encounters the inertial mass of the sea, and sediment carried by the river is deposited as a series of longitudinal shoals in the river and a more wedge-shaped mass of sediment at the river mouth, thus forming the delta. The present delta has six major distributaries and many minor ones. Water depths are commonly only 1–2 m, and shifting channels abound. Older distributary channels and shoals, now abandoned and lying above present sea level, form the vegetation-covered islands of the delta (Fig. 44). The cemetery is located on one of these sandy islands.

Figure 44.

Islands and shoals form the delta at the mouth of the Coppermine River. Ancient deltaic deposits lie in the left foreground. Kugluktuk is in the upper left corner. Photograph by L.A. Dredge. GSC 2000-012X

Discharge

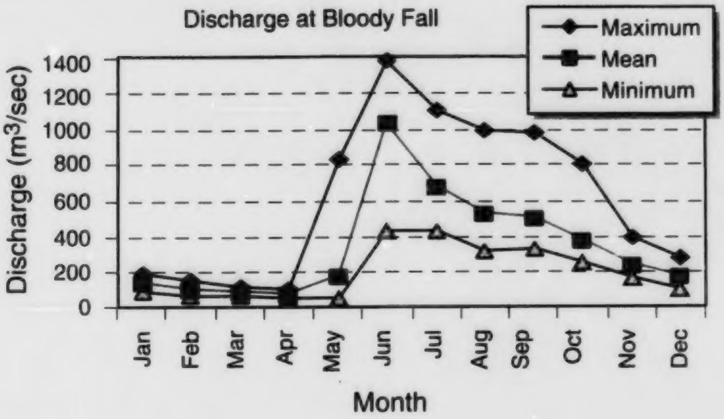


Figure 45. *Discharge graphs showing the amount of water flowing through the gorge at Bloody Fall. Data courtesy of Environment Canada, 1999.*

The amount of water flowing in the river (called the 'discharge') at various places and at various times can be shown as a set of graphs. Discharge increases from the source areas at Lac de Gras down to the mouth of the river, as evidenced by average discharges of 108 m^3/sec (cubic metres per second) at the outlet of Point Lake (about 300 km from the mouth), 255 m^3/sec at Copper Creek (75 km from the mouth), and 348 m^3/sec at Bloody Fall. At a given place, such as Bloody Fall, flow varies from year to year, and from season to season within any given year (Fig. 45). Water flows throughout the year, although the rate is considerably less in winter, when parts of the river system are frozen over, than in summer. The greatest discharge generally occurs during the snowmelt period in early June. The average flow at Bloody Fall in summer is around 1000 m^3/sec. The years 1986 and 1999 had higher-than-normal discharge, and river levels were therefore about 0.5 m above average.

Sediments

River-bed sediments are exposed in several places. Just below Bloody Fall are boulder piles and boulder rapids, large-sized sediments deposited by the river when it slowed and no longer had the carrying capacity to transport them. Sandy terrace deposits are exposed above marine silt in gullies along the west bank of the river (*see* Part IV, Stop 28). Finer, sandy sediments are exposed at low tide on the longitudinal bar at the river mouth (*see* Part IV, Stop 10). This bar is covered with small, current-formed sand dunes and ripples. Although we cannot see the other sediments deposited on the bed of the river, older analogues are visible in cuts along the river bank and in the sand pit south of the airport. Most of the river sediment is medium sand or small pebbles (*see* Fig. 33, 'Alluvium'), laid down in crossbeds. The crossbeds shown (Fig. 46) are cutaway sections of small dunes that formed on the river beds. Layers of sediment cut across one another because of changes in current velocity over time or migration of the main current within the river channel. Smaller lens-like structures within the crossbeds are sand ripples.

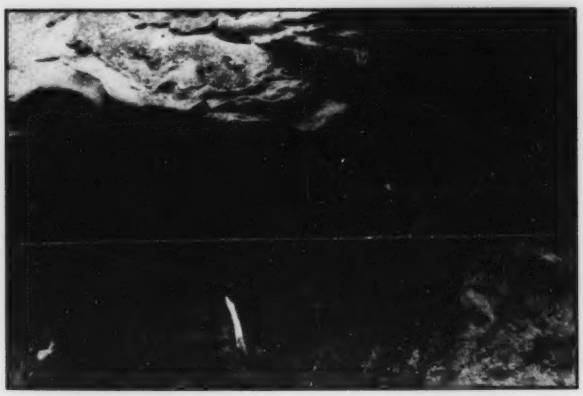


Figure 46. *Crossbeds created by the ancient Coppermine River. These beds of sand and pebble gravel* (see *Fig. 33, 'Alluvium'), dip downward towards the north (left), the direction of current flow. Delicate wavy structures below the knife blade are a cutaway view of the remains of ripples on a former river bed. Photograph by L.A. Dredge. GSC 2000-012Y*

Figure 47. Deltaic sediments exposed in bluffs near the mouth of the Coppermine River consist of beds that slope gently toward the north, capped by horizontal sand layers. Exposure is about 5 m high. Photograph by L.A. Dredge. GSC 2000-012Z

Some sediments in this Arctic environment are the product of river ice rather than flowing water. In winter, a layer of ice covers the surface of the river. At Bloody Fall, this builds up into irregular mounds and sheets that have been thrust upward by the current. Downstream, a horizontal scour line along the river banks about 4 m above the summer water level marks the ice limit at the time of spring breakup. Boulders that had been carried on the ice are embedded in the silty river banks near the falls. Where river ice has hung up on fan debris at the base of the gullies below the fall, irregular mounds of river ice and sediment can persist throughout the summer (*see* Part IV, Stop 25).

Old delta sediments exposed in the eastern bank of the lower Coppermine River show how the river deposits its sediment load as it enters the sea. Uniform, medium-grained sand, slightly finer than that found upstream (Fig. 47), is deposited in regular, planar beds that slope out to sea at an angle of about 3°. These are called 'foreset beds' or 'foresets', and they correspond to deposits that have tumbled over the seaward edge of the modern delta. Each bed represents a sedimentation event. Capping the sloping beds are sand deposits that are more horizontally bedded, called 'topset beds' or 'topsets'. These deposits correspond to the shoals that form the beds of the distributaries of the modern delta, where the effect of river currents is still felt. Beyond the delta, farther away from currents, the size of the material deposited gets finer, until it eventually becomes true marine silt.

Small streams

Below Bloody Fall, large gullies more than 80 m deep have cut down through easily eroded sand deposits of the old postglacial deltas, and then incised more deeply through the underlying silty sand. Deep gully erosion may have begun where rivulets, initiated from melting ice wedges, eroded back into the bluff. The loose sand would have been easily eroded. Once the rivulets became deeply incised, thereby exposing new cliff faces, secondary gullies would have developed, creating the pattern seen today. During heavy rainfalls, considerable amounts of sand are redeposited into the Coppermine River at the mouths of these gullies.

Numerous creeks flow gently across the coastal plain toward the sea. Many of these are most active during snowmelt or heavy rainfall, but have very little discharge during the rest of the year. Those creeks flowing through sand generally have straight reaches and braided beds, whereas those flowing primarily through silt have meandering courses.

Fluvial landforms

Canyons or **gorges** develop where the Coppermine River has eroded deeply through bedrock, due to steady uplift of the land after deglaciation. The river narrows and has almost vertical walls, and rapids form the river bottom (*see* Fig. 43).

Braided river patterns result when there is a high sediment load and the river channel migrates. A braided stream is one that is so full of sediment that it divides and recombines, forming numerous, ever-changing channels (Fig. 48).

Meanders form broad semicircular curves that develop as the river erodes the outer bank of a curve and deposits sediment against the inner bank. The Coppermine River is a gently curving, rather than meandering, river. Some of the smaller streams in the region are better examples of meandering river systems (Fig. 49).

River terraces are flat surfaces beside a river that have been either deposited or eroded by it. Most terraces along the lower Coppermine River are erosional forms produced by incising of the river as the land emerged from the sea (*see* Part IV, Stop 10).

Sandbanks form in the intertidal area of the river. Most form longitudinal bars. At low tide, the exposed bars show a surface of small asymmetric dunes whose steeper flanks are on the down-current side.

Gullies develop in postglacial deposits where streams have incised through easily eroded postglacial sand and clay. Those downstream of Bloody Fall are up to 80 m deep.

Debris fans form at the mouths of stream gullies where sediment, eroded during severe storms, has flowed out of the gullies into the Coppermine River, partially blocking it. Where debris fans flow on top of river ice in the spring, the sand insulates the ice and delays its melting, leaving irregular sand humps cored by river ice.

Boulder piles, consisting of well rounded boulders of various rock types, result from the tumbling of rocks in the highly turbulent waters near Bloody Fall. The size of the boulders attests to the carrying capacity of the river.

Scour lines develop where pans of river ice gouge against the valley walls during spring breakup.

Icings are sheet-like masses of ice that form when a layer of water spreads over frozen parts of the river, and then freezes onto the ice. Where this occurs at the foot of Bloody Fall, layered mounds are built up over the winter. Flatter forms develop along other creeks or where water seeps out at the base of hillslopes during freeze-up.

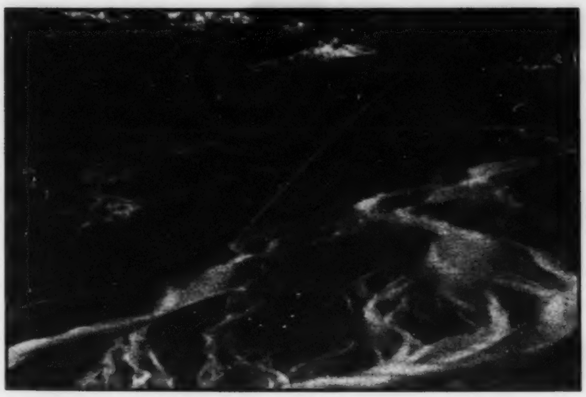


***Figure 48.** Small, braided streams occupy the floors of the gullies at Bloody Fall. Photograph by L.A. Dredge. GSC 2000-012AA*

***Figure 49.** Meandering river inland from Klengenberg Bay. The river channel has cut broad, semicircular curves into postglacial marine deposits. Ice-wedge polygons are visible on the sandy bends in the foreground. Photograph by S.A. Wolfe. GSC 2000-012BB*

A **delta**, such as the modern delta of the Coppermine River, is the body of sediment that develops in the ocean at the mouth of a river. Deltas are commonly composed of islands of sediment and submerged sandbanks, separated by shallow channels (distributaries) that slowly shift their position. A series of old postglacial raised deltas form flat or gently sloping terrain between present sea level and an elevation of 170 m. Ancient distributary channels can be clearly seen on photos taken from the air.

The sea and the coast

Coastal processes

Coastal processes have progressively reworked glacial and postglacial marine sediments since the land began to emerge about 10 000 years ago, depositing a layer of beach sand over older marine sediments. The land surface is presently emerging at a rate of 20–50 cm per century, so that new beaches are slowly being formed in front of older beaches. There has been little change in the shoreline over the last 40 years, in part because of limited open-water periods. The small tidal range, about 1 m, is also a factor that limits the range of wave activity.

Solid ice covers Coronation Gulf from November until the beginning of June, when it begins to break up in the western part of Dolphin and Union Strait (Fig. 50). Shore leads also open up along the south shore of the gulf around the beginning of June, partly in response to discharge from the Coppermine River. In an average year, the ice edge migrates from Dolphin and Union Strait into the western part of the gulf in the first week of July. Sea ice has been cleared from the western gulf by mid-July, but eastern parts remain more than five-tenths ice covered. The entire gulf is clear by mid-August. Ice begins to re-form in early October, and the gulf is usually frozen over by November 1.

Waves are the main agents of coastal erosion and deposition, although currents generated by the Coppermine River have a local effect on the coast. The south shore of Coronation Gulf is fairly shallow, producing a low-energy wave environment (Fig. 51). Higher energy environments operate on the offshore islands, where water is deeper and winds are stronger. Waves and currents are only operative for a short time each year, so their overall effect is less than in more southern latitudes.

The coastline of Kugluktuk is one of net deposition. Waves transport sand and deposit it along the shore. Most beach deposits consist of light quartz and feldspar grains, but a thin layer of black magnetite grains is commonly left on the upper part of the beach after storms. Although there are small cutbanks

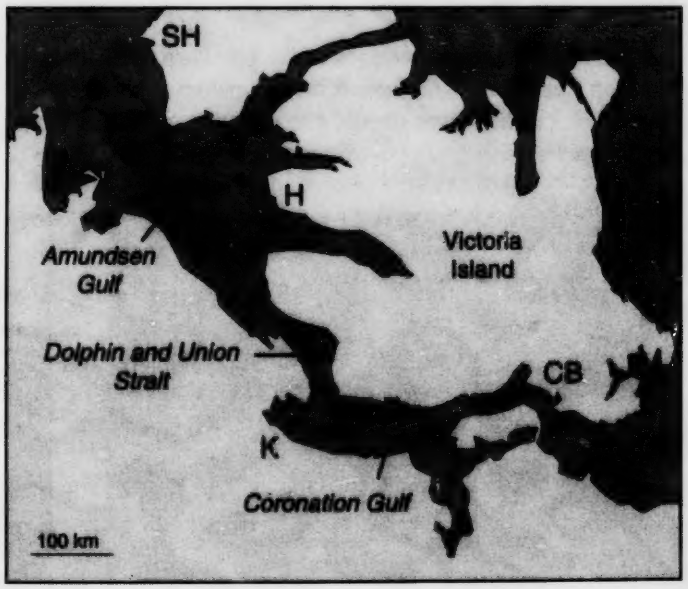
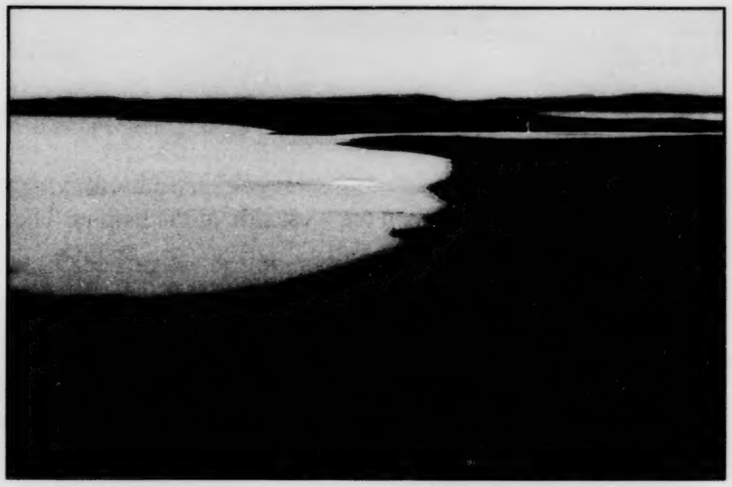


***Figure 50.** Sea-ice cover (in tenths) in mid-July in an average year (*from *Markham, 1981). Abbreviations: CB, Cambridge Bay; H, Holman; K, Kugluktuk; SH, Sachs Harbour.*

Figure 51.

Sandy beaches, like this one on the outer part of the delta, are typical of the south coast of Coronation Gulf. The waterways in the background are delta distributary channels. The low ridge above the boat is an abandoned beach that formed when sea level was higher. Photograph by L.A. Dredge. GSC 2000-012CC



where waves are eroding old beach ridges, the eroded material is deposited nearby in the foreshore, resulting in a flattened beach profile rather than an eroding one.

Coastal landforms

Raised marine plains are the coastal plains that form an extensive area of low relief inland from Kugluktuk. They developed as the land emerged from the sea after the ice sheets melted. The marine plain consists mainly of sandy deposits, including raised beach ridges, underlain by silty clay.

Beach ridges or **beach berms** are low ridges of sand and gravel that form at the back of beaches where waves, rushing up the beach, deposit the sediment they carried. The crest of the ridge separates the beach foreshore from the backshore area.

Raised beaches are flights of abandoned beach ridges produced sequentially as the land emerged during and after deglaciation. Around Kugluktuk, they descend from an elevation of about 160 m down to the modern beach. Between Kugluktuk and 4-Mile bay, the raised beaches consist of sand. On the offshore islands, where there is more wave energy, the beaches consist of rounded cobbles and pebbles (*see* Fig. 88).

Placer deposits of magnetite are dark layers on the beach left behind by waves. The sand-sized grains derive from the gabbro sills in the area, and are concentrated in layers on the beach during storms, when waves throw sediment onto the beach. After some of the wave energy has been absorbed into the beach, the waves can carry back lighter minerals such as quartz and feldspar, but are unable to carry back the heavier magnetite particles.

Spits between Kugluktuk and 4-Mile bay are long, low strips of sand that project out from the mouths of small streams entering Coronation Gulf. The sand has been carried onto the nearshore area by stream currents during low tide. These features are covered at high tide.

Symmetric ripple marks, produced by the oscillating motion of waves impinging on the seabed, are short-lived features visible in the intertidal area on the beach foreshore.

Rocky coasts prevail where sills jut out into the sea. Vertical rock cliffs characterize the eastern sides of peninsulas and islands on either side of Expeditor Cove, but sand- and gravel-covered beaches have developed on gentler slopes on the western and northern sides.

Wind

Wind action

Wind is not a major producer of landforms in this area, although winds are sufficiently strong for two windmills to have been installed on the west side of the hamlet. The windmills are connected to the local power grid (Fig. 52).

Wind effects are largely restricted to areas near the coast, where there are bare surfaces of loose sand. Wind effects cease once vegetation cover is well established. Winds mobilize loose sand on the beach and deposit it in layers on the backshore, covering poorly established vegetation on the top of the beach ridge. Over the years, about a metre of wind-blown sand, interspersed with vegetation layers, has accumulated. Wind also produces asymmetric ripples on the surface and backshore of the beach.

Wind erosion and deposition are also active along the high bluffs directly north of Bloody Fall. Here, winds sweep upward over the cliff face, entraining postglacial sand that forms the faces of the gullies and depositing it on the top terrace at the edge of the cliff. Wind dunes have internal structures composed of crossbeds that are more steeply inclined than those associated with river erosion and deposition, because of their deposition in a subaerial rather than a fluid environment.

Figure 52. *Recently installed windmills provide a local source of renewable energy for several buildings in the community. Photograph by L.A. Dredge. GSC 2000-012DD*

Eolian landforms

Eolian landforms are rare in this area. The main features are **layers of light-coloured wind-blown sand** that lie on top of the ridge directly behind the present beach. Eolian deposits are recognizable by their pale colour, since only the lighter minerals (quartz and feldspar) are generally carried by the wind, and also by the layers of roots between the sand layers. The horizontal layers of rootlets and dark organic material represent the remains of vegetation mats covered by successive periods of wind activity.

Small **dunes** (mounds of wind-blown sand) lie on the high-terrace surfaces near the edge of the gullies on the way to Bloody Fall, where winds have carried loose sand upward from the gully walls. Where the dunes are partially eroded, internal structures (mainly crossbeds) are visible. Each bed marks the slipping of sand grains over the crest of the dune onto the lee-side face.

Blowouts are small depressions in dune areas created by wind erosion of loose sand, leaving shallow, dish-shaped hollows.

Peat and organic terrain

Landforms in organic wetlands

Although peat accumulates slowly in this arctic climate, two types of landforms have developed: palsas and string bogs.

Palsas are low mounds of peat with cores of massive ice or numerous ice lenses. Palsas develop as ice aggrades in peat or silt, pushing up the organic layer in the wetland. In summer, when the surface of the raised-up peat dries out, it has an insulating effect, preventing the ice in the mound from melting. Several small palsas are growing in the wetland east of the ATV track south of Heart lake.

String bogs are visible off the west end of the airport runway and south of the sills near the quarry. A string bog consists of wetland crossed with strips of peat about 10 cm high, separated by shallow pools. The peat strips are oriented at right angles to water flow in the wetland. Therefore, where the land is sloping, the strips are linear and oriented transverse to the slope; on flatter terrain, they develop into loopy, irregular patterns.

PART IV: GEOTOURS

Rock around the clock: a tour of Kugluktuk

The hamlet office is a good starting point for any tour of the landscape. The Sustainable Development Office provides information and several pamphlets on wildlife in the area, and has a variety of displays. You might even get a free cup of coffee as you browse! The Kugluktuk Administrative Office next door distributes a brochure that will help you navigate around the town. The numbers of the stops described below correspond to those on Figure 53.

Stop 1: Hamlet office

As you step out the front door of the hamlet office, your tour of the ice ages begins. You will notice several almost-flat rocks in the grassy area to the east (your right). These outcrops have faint scratches, or striations, that were made by pebbles, entrained in the base of a glacier, dragging across the rock surfaces (Fig. 54). These striations show up best after a rainfall, when the sun glints on the wet rock surface. By looking at the direction of the striations, and the way in which one set crosses another, the sequence of glacier flow directions can be reconstructed. Here, the oldest striations are from inland ice sheets heading toward the north (338°). These are cut by later striations that indicate a change in the direction of flow toward the northwest (312°), then west (270–190°). Finally, some rock surfaces have striations indicating a late ice flow to the southwest (244°). Striations on the rocks directly behind the hamlet office show the same pattern.

The grasses here grow on postglacial marine sediments. Directly overlying the bedrock near the striations are small muddy areas of grey, silty clay that were deposited in a marine environment when sea level was up to 160 m higher than at present, about 100 m higher than the top of Saddleback hill. In other

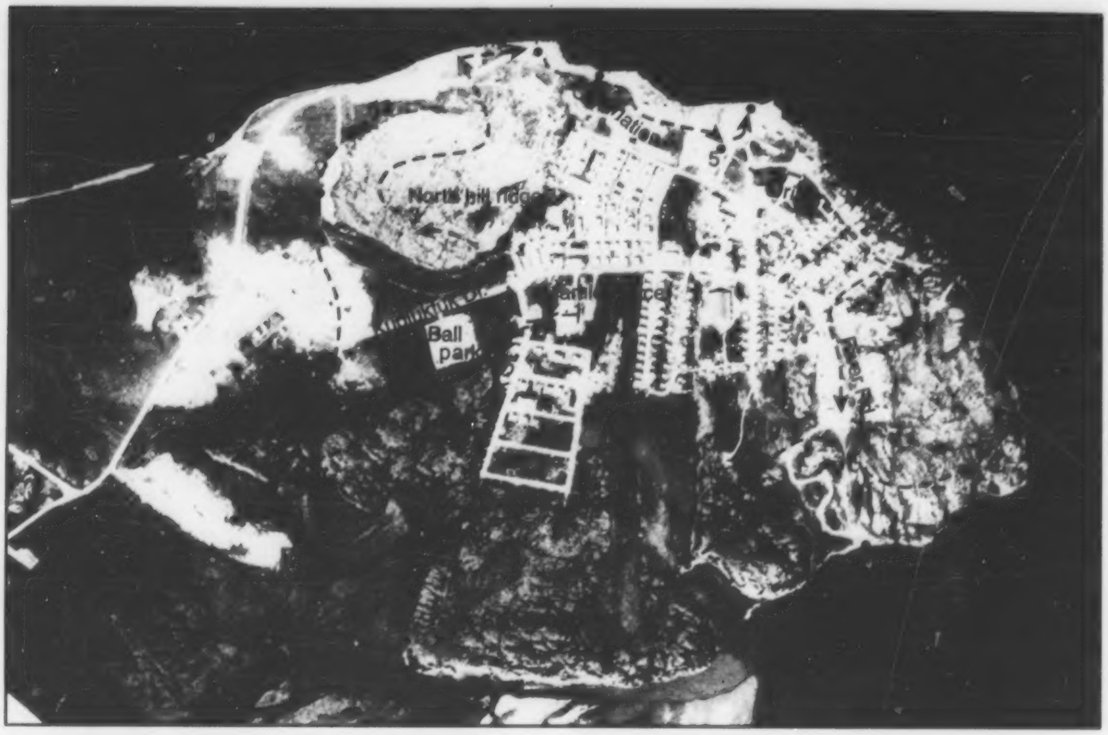


Figure 53. *Locations of stops for a clockwise geology tour around Kugluktuk. Numbers correspond to the stop numbers in the text. NAPL A 27935-78*

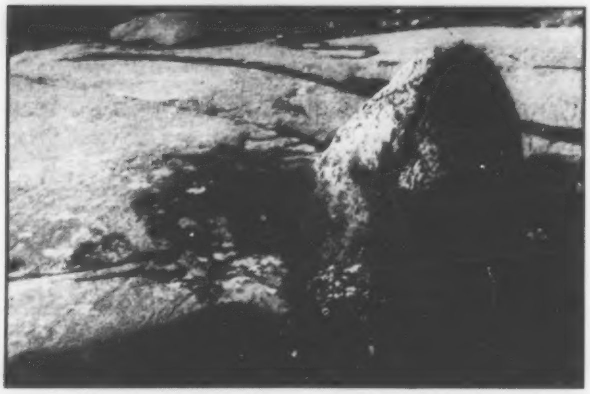


Figure 54. *An outcrop of bedrock at the hamlet office has been abraded and scratched by passing glaciers. The glacier that created these scratches (striations) flowed to the west. Note that the surface of the boulder sitting on the bedrock is crumbly and weathered brown. Note compass to the left of the boulder for scale. Photograph by L.A. Dredge. GSC 2000-012EE*

parts of the grassy area, these fine-grained deposits are overlain by sand, an ancient beach that formed as the land emerged from the sea. The pattern of sand over clay over bedrock is repeated in many places throughout Kugluktuk.

The bedrock itself is gabbro (a rock solidified from magma), the same as that which forms all the other surface outcrops. The outer part of the rock has turned brown due to the weathering (rusting) of iron minerals, but freshly exposed rock surfaces are greenish black. Gabbro boulders lying on the bedrock surface are more intensely weathered, and have brown, crumbly surfaces.

Proceed to the corner of Saddleback Street.

Stop 2: Whalebacks and roches moutonnées

The small outcrops near the roadside along Saddleback Street between the Enokhok Inn and Tuktuk Road show some good examples of whalebacks, rock forms shaped and streamlined by the eroding glaciers that flowed over them. The orientation of these features, and that of the striations on their surfaces, is west (270°), indicating that they formed during the last part of the last glaciation, when the glacier flowed along Coronation Gulf.

This area affords a good point for viewing a large roche moutonnée, another bedrock form shaped by the glacier (Fig. 55, 56). The entire outcrop above the ball park has been shaped by the major ice sheet that flowed north. The ice polished, abraded, and shaped the side facing toward the advancing ice (the up-glacier side), and plucked or tore off large blocks of rock on the down-glacier or leeward side, leaving a craggy north face. This style of asymmetric shaping and streamlining of rock is visible at all scales on many outcrops around the hamlet. In fact, smaller streamlined and plucked forms are superimposed on the larger surface. Some of these are oriented in the same direction as the large hill form, while other small ones are oriented differently, by the later glacier that flowed toward the west (280°).

Continue clockwise around the edge of the hamlet and climb up onto North hill

Figure 55. *This large roche moutonnée on the West rocks has a smooth, glacially polished surface on one side, and a rough, glacially plucked face on the other. Photograph by L.A. Dredge. GSC 2000-012FF*

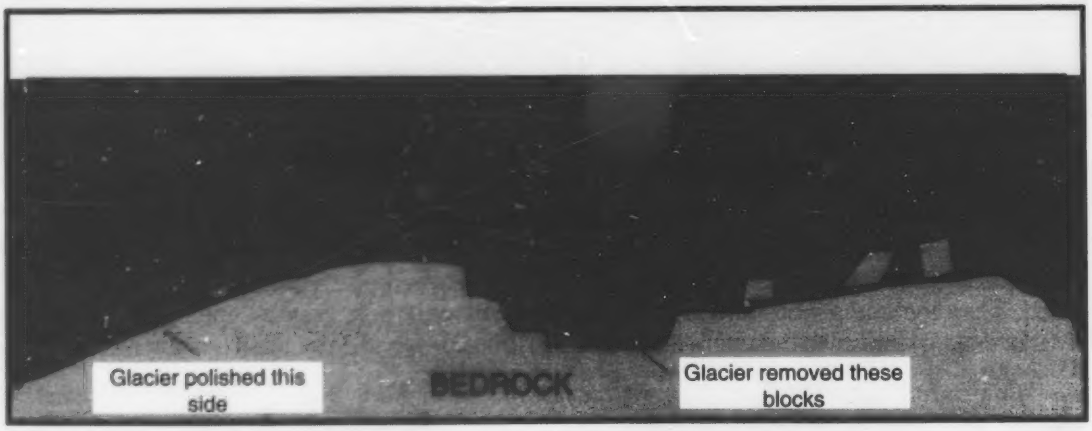


Figure 56. *Diagram showing the formation of a roche moutonnée.*

Stop 3: North hill

The top of this ridge affords a good view of Kugluktuk and also of the offshore islands. You are standing on one of the gabbro sills, the distinctive intrusive rocks on which the hamlet is built. The rocks slope seaward, in the direction of slope of the older sedimentary rocks into which they were intruded about 720 million years ago. Similar sills form the offshore islands, the ridge beyond the airport, and the hills seen in the distance to the west.

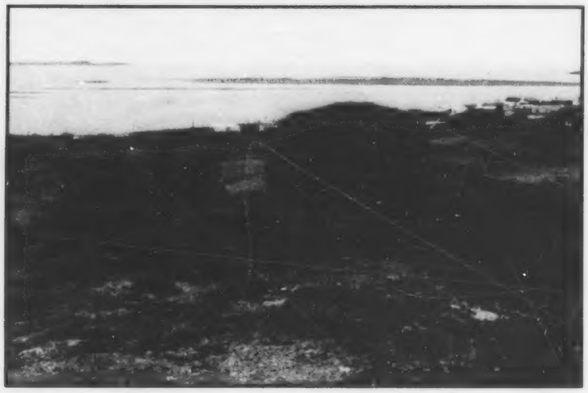


Figure 57. *Heaved blocks of gabbro bedrock on North hill, and surrounding remains of blocks that have been frost shattered. The delta is in the background. Hammer on the left-hand boulder is 35 cm long. Photograph by L.A. Dredge. GSC 2000-012GG*

Glacial striations are not well preserved on this rock surface, possibly because waves of the postglacial sea eroded them away from this exposed slope. Two landforms that are well developed on this surface are rock jumbles and rock panels (Fig. 57). Both forms result from thrusting of parts of the rock surface above adjacent areas by frost heave. The jumbles result when freezing water splits the rock and forces up the fragments. The large blocks or panels are heaved up intact, so that the top surface is relatively undisturbed. Panels tend to be jacked up during a number of heaving episodes.

The west side of the hill offers a view of the windmills built to test the viability of using a local energy source. The windmills are hooked into the local power grid.

Head down the slope of the rocks to the campground and boat-launch areas.

Stop 4: Boat launch striations

The best striations in Kugluktuk are exposed near the shed at the boat launch, although they are being worn away by boat trailer gouges. Here, glaciers repeatedly scratched this flat rock surface. The earliest ice flowed north and produced a glacial surface that is preserved on the west part of the bedrock outcrop (Fig. 58). A second, later ice flow then produced most of the striations, which trend west on the main part of the outcrop. A final, weaker ice flow from Coronation Gulf heading inland toward the southwest then produced fine, faint striations that are found only on the seaward side of the outcrop.

Glacial erratic pebbles and cobbles can be seen in the shallow water at the campground. The range of different rock types represented in the erratics reflects the various bedrock types that the glaciers passed over and eroded. They include gabbro and argillite from nearby outcrops; granite, gneiss, and red and green argillite from distant sources to the south; and quartzite, limestone, and dolomite from outcrops to the east.

Continue along Coronation Drive. You will pass the swimming beach, RCMP headquarters, the Coppermine Inn, and the Catholic Church (Our Lady of the Light). From the Renewable Resources Office, you can obtain information about hunting and fishing in the area.

Figure 58.

Glacial striations on highly polished bedrock surfaces record an early northward ice flow (parallel to the white pencil), followed by an ice flow to the west (parallel to the black pencil). Photograph by L.A. Dredge. GSC 2000-012HH

Stop 5: Visitors' centre

Opposite the gas bar is the visitors' centre. Displays and a video will introduce you to the people and history of Kugluktuk, and your questions about the town will be answered by helpful volunteers. Carvings, sewn crafts, and paintings by local artists can be purchased here, or at the Northern Store or Co-op.

Stop 6: Sea-lift dock

In summer, the sea-lift dock is a hive of activity. The dock lies at the edge of one of the distributary channels of the delta. Because water depths are only 1–2 m, boaters generally pole out from the dock before starting the engines (Fig. 59).

Looking offshore, you can see some of the barely submerged migrating shoals that form active parts of the delta, where sandy sediment carried by the Coppermine River is deposited. Beyond the channel are slightly emerged bare islands, also part of the present delta, and higher, older islands that no longer flood over and are now covered with grassy vegetation.

Along the shore to the right and left of the dock are small bluffs about 1 m high. Sandy sediments form the vertical part of these bluffs, but postglacial marine silt is exposed at the base.

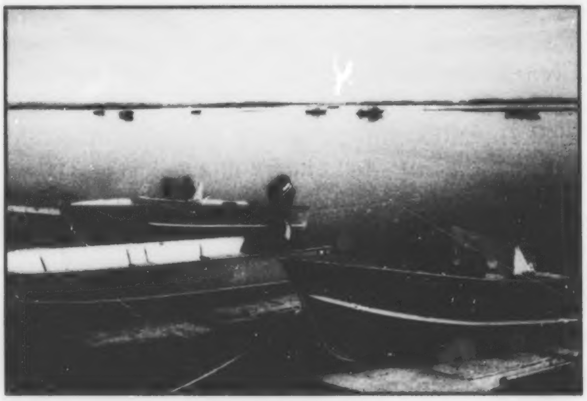


Figure 59. *Delta shoals and glassy water at the main dock, Kugluktuk. Photograph by L.A. Dredge. GSC 2000-012II*

Continue along Coronation Drive, past the red-roofed old Hudson's Bay Company buildings and St. Andrew's Anglican Church, to the end of the road at the boat 'Nassivak'.

Stop 7: Corestones and erratics

Near the boat are outcrops of weathered gabbro bedrock. There is a good example of rounded 'corestones' of fairly solid rock, surrounded by crumbly rock and mounds of disintegrated granular material, called 'grus', that have dropped off the weathered surface (Fig. 60). Gabbro usually weathers fairly rapidly when exposed to the air because the iron minerals oxidize. Several agents help in the weathering process by exposing fresh rock surfaces to the air: frost shattering, lichens, salt-water spray, and expansion and contraction due to alternating warm and cold temperatures.

Proceed to the rocks above the municipal water intake.

You can either cross overland behind the houses or go up through the old town via Klengenberg Street and River Road. If you cross over the rocks, you will see some examples of glacial erratics: in this case, large boulders of granite, gneiss, and quartzite transported by glaciers from areas to the south. Also, as you cross a rough track that goes down to the shore, you will see small outcrops of columnar gabbro. The 'columns' result from the distinctive style of fracturing into six-sided columns that is associated with the cooling of this rock from magma. As the rock solidified and cooled, the contraction fractures formed.

Figure 60. *Lichen-covered gabbro bedrock at the end of Coronation Drive, showing a surface of solid rock surrounded by crumbly weathered rock ('grus'). Photograph by L.A. Dredge. GSC 2000-012JJ*

Stop 8: East point

This area is a high cliff that overlooks the Coppermine River, the modern delta, and the surface of the delta that formed about 3000 years ago, which now forms a plain on the far side of the river. The modern delta complex consists of shallow distributary channels where the Coppermine River empties into Coronation Gulf, and intervening shoals and islands (Fig. 61). The nonvegetated flanks of the large island are part of the modern delta, but the vegetated part lies above the floodline and is no longer a functional part of the active delta. It was abandoned about 2000 years ago, although old distributary channels are still visible on its surface. The bluff below the cemetery (which can be seen from stop 8) on the island is made of sand that has structures typical of deltaic sediments.

Other parts of an old delta from about 3000 years ago now form the east bank of the river. The river now cuts through the old delta sediments, exposing them in a river bank that is up to 8 m high. Several 'dips' in the almost flat delta surface are outlines of old distributary channels that once flowed across the delta.

From East point, you can also see the back of the rock face formed by the sill to the west, which is about 50 m high. The columnar joint pattern characteristic of these rocks is apparent on the vertical face. The tops of the columns have been eroded and abraded by glaciers advancing from inland ice-flow centres toward the north (350°). Large-scale features shaped by this northward ice flow have been reshaped in some places into smaller streamlined forms and roches moutonnées by later glaciers flowing west.

Figure 61. Coppermine River delta, with islands, shoals, and distributary channels, both old and modern. Kugluktuk is in the upper right corner. Arrow indicates location of cemetery. Photograph by L.A. Dredge. GSC 2000-012KK

On the rock surface at East point are good examples of frost-shattered bedrock in a variety of forms. They developed in the same way as those noted on North hill and on the ridge above the ball park.

Cross over to the upper part of the road leading to the municipal water intake. A plaque outlining the development of the community has been erected here.

Stop 9: Water-intake road

Across the road on the soil surface below the transmission tower are patches of grey silt that form circular features called mud boils (Fig. 62, 63). Other mud boils occur in the low, wet areas of Snowboard hill, between here and Saddleback hill. Mud boils are the result of complex frost-churning of sediment, which comprises upwelling of wet silt in the bare central parts of the mud circles, frost thrusting of pebbles and other material outward from the centre, and downward movement of materials by gravity at the perimeter of the feature. These actions form a circulation cell in the ground that constantly churns up fresh material into the central part of the mud boil, preventing vegetation from becoming established.

The small outcrop across the drainage ditch from the mud circles is a classic roche moutonnée, shaped by a glacier flowing to the northwest. The southeast side has been abraded, polished, and striated, and the northwest end has been plucked away, leaving a vertical face on the glacial lee side.

Figure 62. The bare, circular patches on these marine silt deposits are mud boils produced by frost-churning of the active layer. Photograph by L.A. Dredge. GSC 2000-012LL

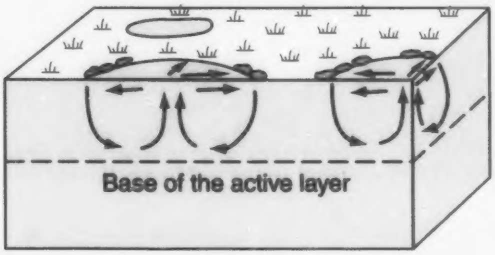


Figure 63. Cutaway diagram showing the frost-churning process that forms mud boils, with arrows indicating the direction of churning. Vegetated areas are stable.

Cross over onto Saddleback hill. You will pass rock outcrop on which two ice-flow events are recorded: one northwestward, indicated by striations and streamlined rock forms, and the other westward, indicated by striations. The low areas between rock knobs contain postglacial marine silt, and some beach gravel. Fragments of marine shells lie on the surface in a few places.

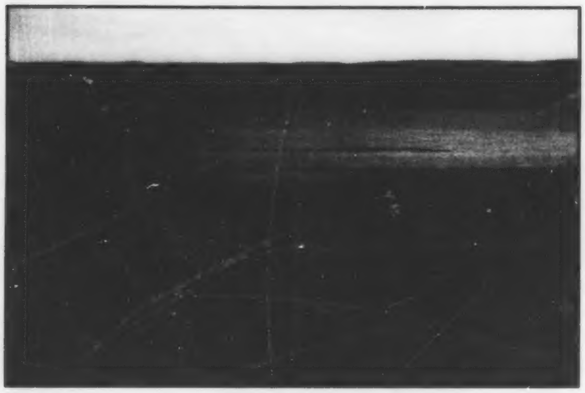


Figure 64. *Foreground shows asymmetric ripple marks produced by river currents on a bar in the Coppermine River. An old delta surface, now standing 5 m above sea level, lies on the other side of the river. Ripples are about 8 cm high. Photograph by L.A. Dredge. GSC 2000-012MM*

Stop 10: Saddleback hill

The top of Saddleback hill provides an excellent vista of the Coppermine River. Former river terraces and old delta surfaces, which form the plains between the hilltop and Bloody Fall, fill the view to the south. The rock ridge at Bloody Fall forms the skyline on a clear day.

At low tide, small sand waves created by river currents are exposed on the bare sandy shoal lying below the first river terrace (Fig. 64). Above this is a series of progressively higher and older river terraces, now abandoned, that formed as the river cut through older marine and deltaic sediments.

Looking seaward, the hill also provides an excellent view of Kugluktuk, the coast, and the offshore islands.

Like the other ridges, Saddleback hill is a gabbro sill that was intruded into sedimentary rocks, now exposed at the base of the cliff about 60 m below. The rock surface slopes gently northward, parallel to the dip of the underlying strata.

Proceed across the ridge and saddleback to the West rocks. You can do this either by heading north on Saddleback Street, or by crossing along the top of the ridge. If you cross the ridge top, you encounter several low, sandy to gravelly ridges that were beaches about 7000 years ago. Wave action has rounded the gravel deposits.

Stop 11: Rocks above Father LaPointe ball park

On the flatter slopes near Saddleback Street are good examples of frost-heaved rock jumbles (Fig. 65) and large, heaved, rock panels on which the original glacially striated surfaces are still intact.

The rocks above the ball park are those seen from a distance at stop 2. The entire outcrop is part of a large, glacially streamlined rock surface with a glacially plucked north face. On this major

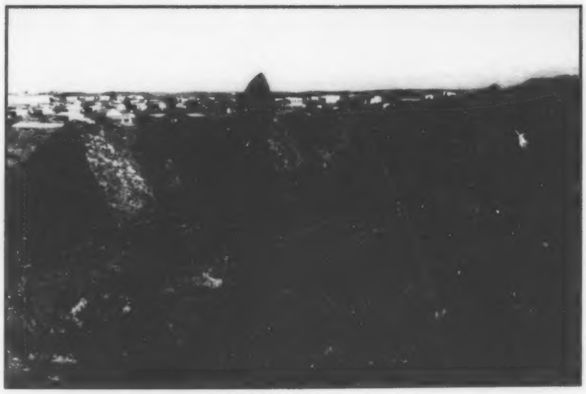


Figure 65.*Jumbles of frost-heaved bedrock are common on the rocks west of the townsite. Photograph by L.A. Dredge. GSC 2000-012NN*

Figure 66. Glaciers flowing from left to right have shaped the surface of this outcrop, producing many small, streamlined landforms. The low gravel ridge in the foreground is an old beach (now 40 m above sea level). Photograph by L.A. Dredge. GSC 2000-012OO

landform and at stop 11A are many smaller, streamlined, glacial whalebacks (Fig. 66; stop 11A) and striations. Some of these were formed by the major north-flowing glaciers that shaped the main outcrop, whereas others were reshaped into west-trending features by later glaciers.

Descend the gravelly beach ridge at the west side of the rocks and proceed toward the old quarry at the base of North hill. As you descend from the beach ridge, which has wave-rounded pebbles and cobbles, you encounter more poorly sorted angular stones of a variety of rock types. These clasts are the remains of till, rock debris eroded from both distant and nearby bedrock, transported by glaciers, and later deposited as the glaciers melted.

Stop 12: Old quarry

The old quarry lies on the west side of town. The sedimentary rocks that are being used for aggregate are exposed below the base of the sills, which are the massive rocks seen above them. The sedimentary rocks are composed of many layers of fine-grained material that has been metamorphosed (altered by heat and pressure) into slate or argillite (Fig. 67). The main beds are easily seen. Each gently dipping layer represents an ancient sedimentation event. Fissures in the rock have been filled with white calcite (Fig. 68), particularly where these rocks have been altered by contact with the intruding magma that formed the sills. Small stringers of magma are visible among the sediments. The calcite veins, particularly those near the magma stringers, contain flecks of pyrite (iron sulphide) and chalcopyrite (copper-iron sulphide). Similar rocks are exposed in the quarries on the way to the airport.

Proceed around to the shore-facing side of the rocks.

Stop 13: Topples

You can see where huge blocks of columnar gabbro have become detached from the main bedrock mass, and are leaning out from the cliff or have toppled to the base (Fig. 69). Topples are also prevalent at the base of the cliff near the ball park. Toppling

Figure 67. Slatey, horizontally bedded, grey and white, metamorphosed sedimentary rocks (argillite) of the Rae Group underlie massive gabbro at the old quarry. Hammer (circled) is 35 cm long. Photograph by L.A. Dredge. GSC 2000-012PP

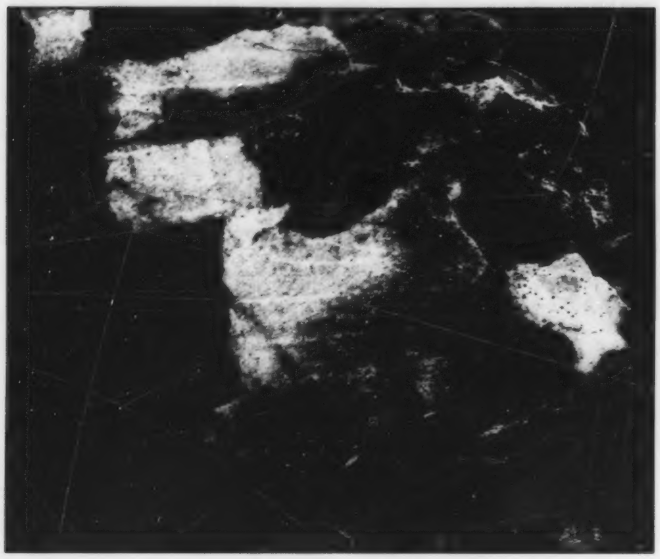


Figure 68.

Close-up of the argillite from Figure 67, with white calcite lining the fissures. Irregular masses and shiny flecks of pyrite and chalcopyrite can be seen on the right. Photograph by L.A. Dredge. GSC 2000-012QQ

Figure 69.

South faces of gabbro outcrops show the columnar fractures typical of these rocks. In some places, large blocks have detached from the outcrop and have moved down slope. Where these have toppled away from the cliff face, they have broken into smaller blocky fragments that lie at the bottom of the cliff. Boulder in foreground is 1.5 m long. Photograph by L.A. Dredge. GSC 2000-012RR

may have begun with glaciers moving loosened rock columns in a down-ice direction, because topples are more common on glacial leeward sides of rock cliffs than on those facing up-glacier. However, present-day frost heave of these loosened blocks has also played a part in the process.

Heart beat

This tour takes you from the west edge of Kugluktuk, near the airport, to Heart lake. The numbers of the stops described below correspond to those in Figure 70.

Tired of swimming at the beach in those icy waters? Have a relaxing warm swim in Heart lake. Proceed from the airport turnoff westward along the road.)

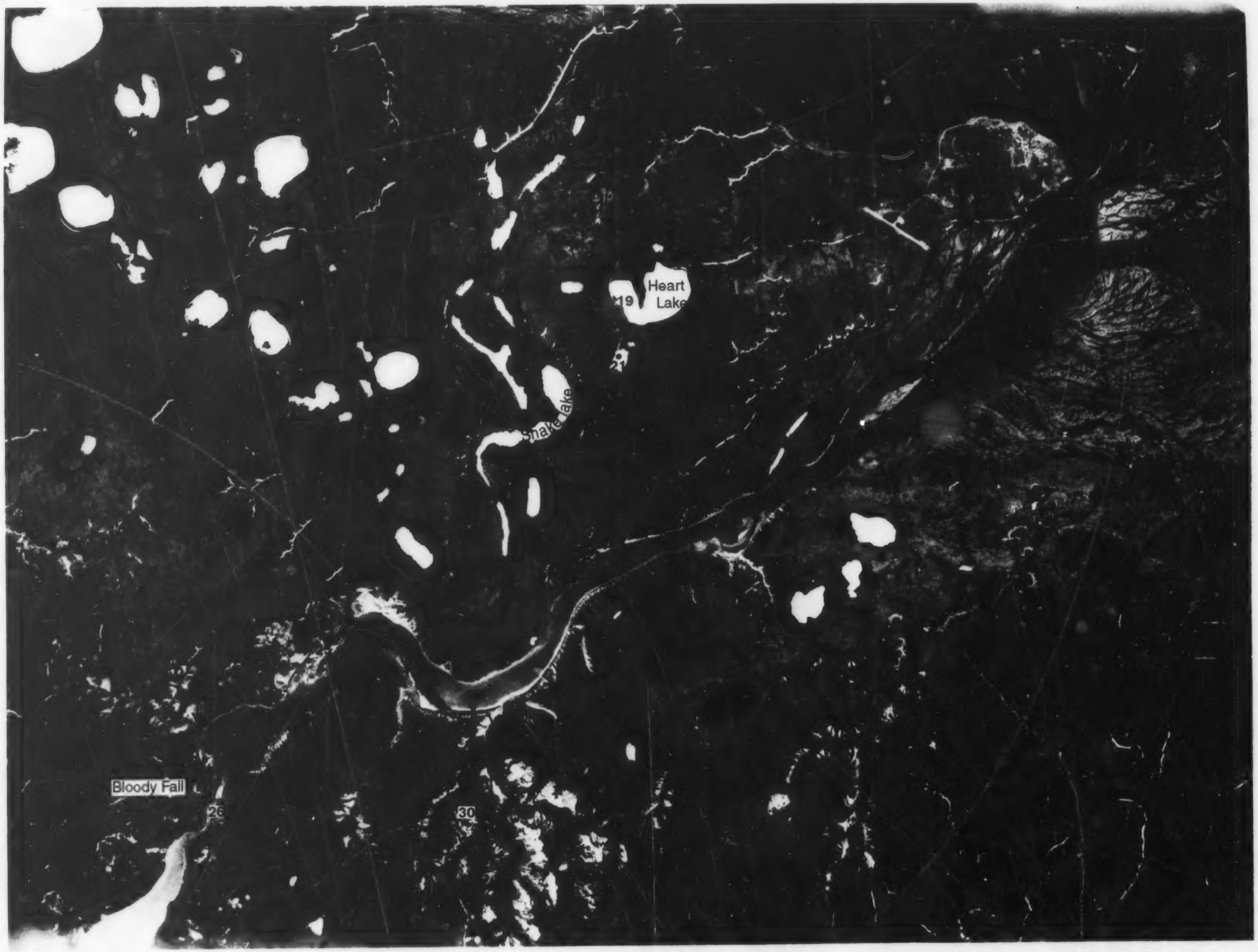

Heart
Lake
19
21
Snake Lake
Bloody Fall
26
30

Figure 70. *Locations of stops between Kugluktuk and Bloody Fall. Numbers correspond to the stop numbers in the text. NAPL A 22435-24, 25.*

Stop 14: Airport rocks

The rock outcrops at the airport turnoff, like most others at Kugluktuk, consist of gabbro that has been scratched and shaped by passing glaciers, flowing first to the north (004°) from ice centres inland, and then to the west, parallel to the coast.

Stop 15: Braided ministream

As you continue along the road, you cross a culvert at the end of the airstrip.

The stream entering the culvert drains a small string bog. On the north side of the road, where the stream crosses some raised beaches, it breaks up into a myriad of small, interconnected rivulets separated by 'islands'. This is a miniature version of a classic stream pattern called a 'braided stream'. The position of the braids varies with stream flow, amount of sediment, and the slope of the stream bed. Similar, larger streams of this type occupy the bases of the gullies near Bloody Fall. The braided stream pattern contrasts with the form of the Coppermine River, which has a slightly sinuous single channel.

Stop 16: Flights of beach ridges

At the first big bend in the road you will see a flight of beach ridges.

These beach ridges rise gently from sea level, where new ridges are being formed, up to the base of the rock ridge at about 40 m elevation, where the beaches formed about 6500 years ago. The sand pits nearby show that the beaches are composed of well sorted, medium-grained sand, deposited in almost horizontal layers. The surfaces of the old ridges are vegetated with dwarf birch and other tundra shrubs, grasses, and lichens. Permafrost lies at depths between 30 and 80 cm, the depth being dependent on the amount of vegetation cover, which acts as insulation. Ice-wedge polygons have developed on the raised beaches. The depressions above the ice wedges are about 40 cm deep, and the polygon networks are roughly rectangular and about 10 m across.

As you continue southward, you pass the remains of a string bog on the left side of the road.

Stop 17: Quarry

At the next curve in the road is a quarry where gabbro is mined and crushed for rock aggregate. You can obtain samples of fresh gabbro from the roadside.

Do not enter the pit without permission.

If you enter the quarry, you will see the columnar structure, typical of this type of rock, on the pit wall. The columns are more visible at the top of the pit face because the rock joints are wider. With depth, the joints narrow until they become merely hairline fractures. The amount of weathering also decreases from the surface, where the rock has been weathered brown and slightly weakened, down to rock that is fresh, hard, and dark green in colour. The green minerals in the rock are pyroxene (an iron-rich silica mineral) and olivine. The grey minerals are mainly plagioclase feldspar.

Stop 18: Rock ridges

If you hike up the rock ridges that stretch away on either side of the quarry, you can have good views of the plains to the south. The flat plains are the old delta. Shallow linear ponds outline former distributary channels. Also visible are V-shaped gullies where streams that flow into the Coppermine River have easily cut through the old delta sand deposits. Directly below the ridge is a string bog, with irregular strips of peat and grass separating shallow pools (Fig. 71). To the right is Heart lake. The serrated skyline to the west is created by successive ridge-forming sills, each sloping to the northeast. The columnar form of the cliff face, and its glacially abraded upper surface, are also noticeable (Fig. 72).

The ridge top itself is littered with glacial erratics and patches of glacial till, left behind by the melting ice sheets (Fig. 73). The erratic boulders include a variety of rock types derived from distant bedrock sources, while the glacial till is a mixture of subangular pebbles, sand, and mud. Boulders and pebbles of granite, gneiss, syenite, basalt, quartzite, dolomite, argillite (red, green, and black), shale, and gabbro are present.

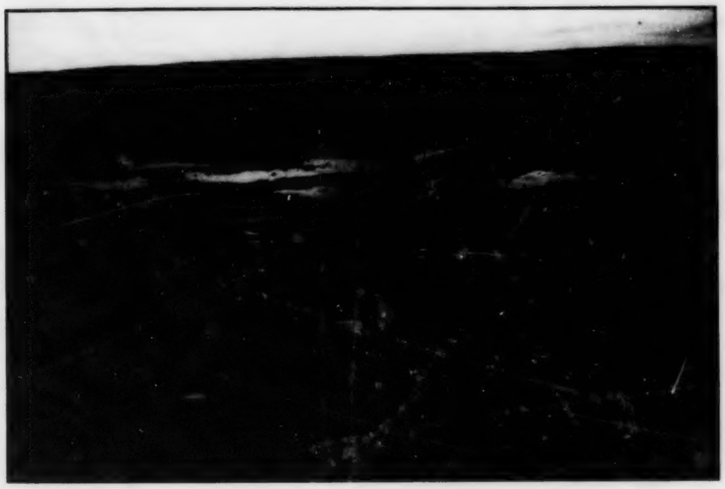


Figure 71.

View from the quarry ridge, looking south over the old, flat, delta surface. A string bog, with shallow pools of water, occupies the foreground. Photograph by L.A. Dredge. GSC 2000-012SS

***Figure 72.** View to the west from the quarry ridge. The distinct columnar pattern of rock joints is clearly visible on the cliff face. The top of the cliff has been abraded and rounded off by glaciers. Glacially transported rock fragments lie on the ridge crest. Photograph by L.A. Dredge. GSC 2000-012TT*

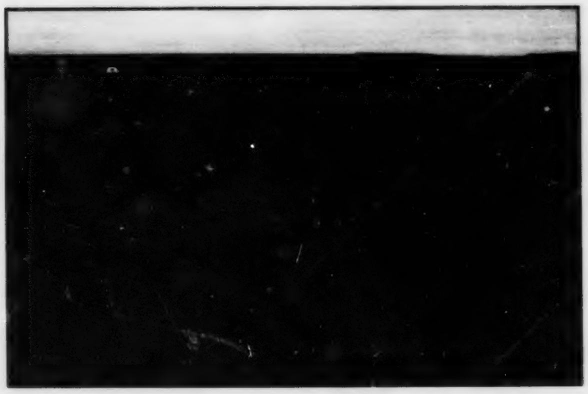


***Figure 73.** Glacial erratics on the quarry ridge. These blocks, of rock types that do not occur in the vicinity, have been transported and then deposited by ice sheets that flowed across the region. Photograph by L.A. Dredge. GSC 2000-012UU*

As you descend back down the ridge, you will cross some bouldery beaches, where the glacial boulders have been reworked and rounded by waves.

On some parts of the ridge, especially directly east of the quarry, there are many examples of frost-split, -heaved, and -shattered bedrock. Most of these fit into the 'rock jumbles' category, but there are also some rectangular rock panels, and circular rock blisters.

Stop 19: Heart Lake

Heart Lake is a flat-bottomed tundra pond that is partly drained, so that a strip of its sandy bottom is exposed along the shore; this has become the ATV drag strip. In mid-summer, water temperatures can be as high as 15°C. A sandy peninsula creates the heart-shaped plan view of the lake. A large postglacial beach ridge forms the south side of the lake, and stands about 3 m above lake level. The beach ridge and surrounding plains support vegetation typical of arctic coastal regions. Woody shrubs include birch, willow, and Labrador tea (*Ledum*); there are several kinds of lichen, an abundance of wildflowers such as lupins and avens (*Dryas*), heather, and small grassy tussocks. The density of tussocks increases in areas that are less well drained. In sheltered depressions, willows reach a height of 2 m (Fig. 74), although they are less than 30 cm high on exposed surfaces. The ground is frozen below a depth of about 50 cm in summer.

***Figure 74.** Willow at Heart Lake that is more than 2 m tall. Photograph by L.A. Dredge. GSC 2000-012VV*

Stop 20: Drained tundra ponds (a side tour for bug-resistant people)

Three flat-bottomed depressions northwest of Heart lake are drained tundra ponds. The water-filled depressions were formed by the melting of masses of ground ice in the surface sand (old beach ridges) and more clay-rich substrate. As gullies eroded headward and inland from the coast, they first breached the rim of the northernmost pond, which then drained. Progressive headward erosion then caused the other two ponds to drain in several stages. Ice-wedge polygons have begun to form on the drained bottoms of these features, but the wedges have not reached the size of their counterparts on the raised beaches because those on the beaches have had longer to form.

Overland to Bloody Fall

Bloody Fall lies 15 km south of Kugluktuk, or about 10 km south of Heart lake. It can be reached overland by foot or all-terrain vehicle (ATV) along a trail that heads southward to the Coppermine River and then follows the west bank of the river around to the fall (see Fig. 67).

Stop 21: Palsa pond and delta surface

As you head south from Heart lake along the trail, you will see a long shallow lake on your left. This lake contains small palsas, ice-cored mounds of peat that have been raised gradually above the water table as ground ice grew and pushed up the organic material on the pond bottom. Palsas are not seen elsewhere near Kugluktuk.

The plains you are crossing are an old delta surface that developed where the ancestral Coppermine River deposited its sediment. Shallow elongated depressions on the surface are old stream distributary channels cut into the delta.

Smaller sets of shallow depressions forming rectangular or polygonal patterns on the surface of the sand plain are ice-wedge polygons. Although the sand plain is underlain mostly by 'dry' permafrost, wedges of ground ice underlie the polygon-forming depressions. Where the vegetation has been removed or compressed by repeated tracking, the ice wedges have begun to melt out, and the troughs have consequently deepened, creating a roller-coaster ride along the trail.

When you reach a steep sand gully, you are at the bluff overlooking Snake lake.

Stop 22: Snake lake channel.

Snake lake lies in an old channel of the Coppermine River that emptied into Coronation Gulf about 6 km west of the present river mouth. The river began to flow in this channel about 7000 years ago, when sea level was about 50 m higher than at present, and continued to flow here until about 4000 years ago. As the land emerged over the 3000-year period when the channel was active, the river incised through its old sediments, creating the bluff.

Continue to follow the trail up the other side of the gully. You will eventually cross into grassy sedge and tussock lowlands of the channel bottom, and then ascend onto the high, flat terraces on the other side. From here the path follows the edge of the terraces along the Coppermine River.

Stop 23: High terraces

The high terraces are part of an older and higher delta that formed when sea level was 80–100 m above present. The early postglacial Coppermine River poured into the sea at this point. Silty deposits that underlie the terraces were deposited in deep water. Coarser nearshore and beach sediments were progressively deposited on top of the silt as the land rose and the sea became shallower. The terraces today contain ice wedges, forming polygonal patterns on the surface (Fig. 75). Small tundra ponds with cotton grass occupy depressions where ground ice has melted out.

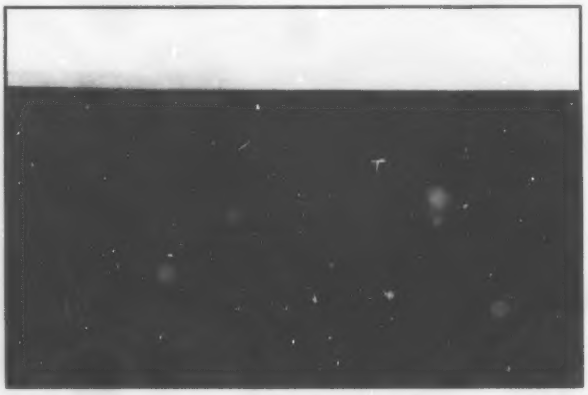


Figure 75. *Networks of depressions on the high terraces mark the location of wedges of massive ice that have developed in the upper parts of the sandy sediments. Small pools of surface water are common where ice wedges intersect. Polygons are approximately 10 m across. Photograph by L.A. Dredge. GSC 2000-012WW*

PaleoIndian archeological sites have been found along the edges of the high terraces. Beaver-incisor chisels, burins made from antlers, argillite lance points, knives, adzes, and antler needles are some of the artifacts left at seasonal campsites occupied by small bands of caribou hunters.

Active eolian dunes, mostly nonvegetated, and shallow blowout depressions lie at the edge of the most northerly part of the high terrace.

Stop 24: Gullies

Gigantic gullies, 80 m deep with cuspate headwalls and steep slopes, form the west bank of the Coppermine River along the last 4 km to Bloody Fall. Thick deltaic sand deposits, whose gently sloping beds indicate that they were deposited by currents flowing to the northwest, occupy the top part of the northernmost gully. The sediment becomes silty toward the base of the gully (Fig. 76). This same silty material forms the triangle-faceted cliffs along the opposite bank of the river. The gullies closer to Bloody Fall consist mainly of coarse sand at the top, which grades down into finer sand rather than silt. Sedimentary structures can be seen in the gully walls. These include horizontal (topset) beds, sloping (foreset) layers, and some contorted zones (load casts) where sediments foundered during deposition. Where windblown sand is present at the top of the bluffs, crossbeds of light-toned sand, interspersed with vegetation (root) layers, cap the old marine sediments.

Three large gully systems are presently active, periodically depositing sandy debris in fans at the edge of the Coppermine River. Several others are partly vegetated and therefore semistable. A few others, with bases that have reached bedrock knobs, are stable and grassed over.

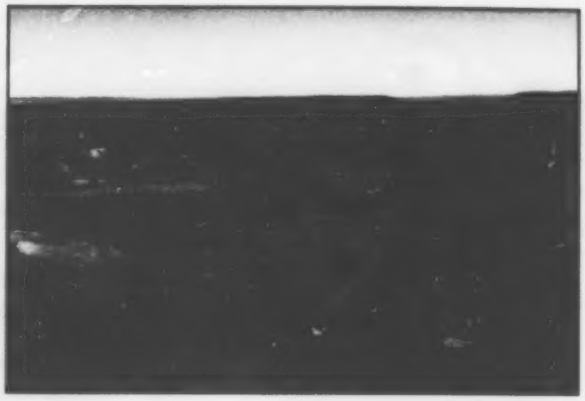


Figure 76. Deep gullies and side-gullies dissect ancient, flat-topped, deltaic deposits near Bloody Fall. In this photo, a thick layer of sand overlies finer silty deposits. Some structures related to the formation of the old delta are visible in the sand deposits. Photograph by L.A. Dredge. GSC 2000-012XX

Stop 25: Debris fans at the bases of gullies

Pans of river ice carrying boulders and gravel have been stranded on the sandy fans at the bases of the gullies. In some places, the ice pans are covered with either river gravel or sand from the gullies, which insulates them and prevents them from melting. The irregular mounds on the debris fans that persist throughout some summers are ice cored (Fig. 77).

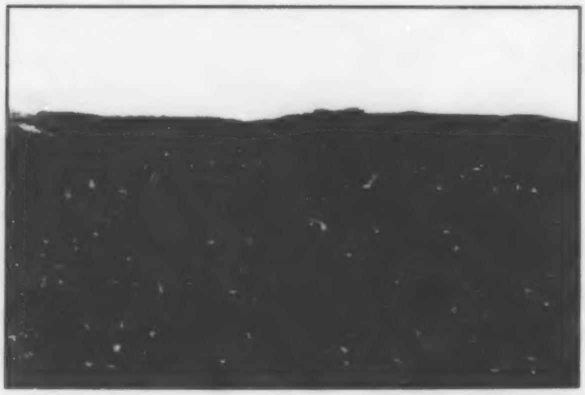


Figure 77. Irregular mounds at river level at the bases of the gullies are cored with flat slabs of river ice. The sediment that has accumulated on top of the ice has prevented it from melting. Boulders and gravel in the foreground have been deposited by the river. Boulders in foreground are approximately 50 cm across and mound is approximately 2 m high. Photograph by L.A. Dredge. GSC 2000-012YY

The small streams flowing in the bottoms of the gullies (Fig. 78) have braided patterns. Braids develop when sediment load is high, rainfall is irregular, and the slope of the channel is steep.

Bloody Fall

Stop 26: Bloody Fall

Bloody Fall (Fig. 79) gets its name from the massacre of a group of Inuit by Indians accompanying Samuel Hearne on a trip down the Coppermine River in 1771. The fall has been a site for human activity over the last 4000 years. Remains of Pre-Dorset and Thule houses and artifacts have been excavated in the area now covered with willow bushes.

From time to time, the willows are frequented by a grizzly as well as by campers, so be careful when exploring in this area.

Bloody Fall is a turbulent chute, created where the river has eroded into, and drops over, a gabbro sill. The columnar style of rock jointing is clearly visible along the bedrock walls of the gorge upstream of the main Fall. Below the chute, where the river has cut into more easily eroded postglacial deposits, it widens, slows down, and deposits much of its bouldery load.

The bedrock surface at the base of the Fall is smoothly polished. Remnants of glacial striations are preserved, particularly where the rock is fine grained. One set of striations points north, the other points west. Striations oriented in other directions, particularly where the scratches look fresh, were produced by clasts pushed and dragged by river ice.

Figure 78. *Steep, sediment-choked braided streams have developed at the bases of the gullies and their tributaries. Photograph by L.A. Dredge. GSC 2000-012AAA*

Figure 79. *Aerial view of Bloody Fall, looking upstream. The gorge is rock walled but, across the river, gentler slopes of postglacial marine silt, capped by sand, are the principal surface materials. Photograph by L.A. Dredge. GSC 2000-012ZZ*

The boulders at the base of the Fall attest to the energy of the river, which has transported, tumbled, and rounded them. The boulders derive from a variety of bedrock sources upriver, including granite, gneiss, volcanic rock, sandstone, and argillite.

A horizontal line engraved into the silty clay banks across the river, about 5 m above the summer water level, is the limit of maximum ice scour in winter. A tremendous thickness of ice builds up in winter, even through the river continues to flow. Below the ice line, gravel and boulders, carried on top of the river ice, are stuck into the clayey slopes.

Kugluktuk to Bloody Fall by boat

As you leave Kugluktuk by boat, you head into the main channel of the Coppermine River. Even here, there are many shoals where the water depth is less than 2 m, and the tidal range is about 1 m.

Stop 27: Old delta and river terraces

The east bank of the lower river is an old delta surface, cut by distributary channels. The river bank consists of medium-grained sand. The uppermost layer is horizontally bedded delta topsets, while the gently sloping lower sand deposits are delta foresets (*see* Fig. 47). These have been cut through by the shallow, flat-bottomed distributary channels that intersect the bluff. The sediments were deposited when this site was at the seaward edge of the growing delta, in a position corresponding to the outermost part of the present delta.

On the west side of the river are bare longitudinal bars, exposed at low tide, and above them are abandoned alluvial (river) terraces formed when sea level and river level were higher than at present (Fig. 80).

***Figure 80.** Ancient raised, and modern lower, terraces and channels dominate the landscape along the lower Coppermine River. View north toward the delta and Kugluktuk. Photograph by L.A. Dredge. GSC 2000-012BBB*

Stop 28: Deepwater marine deposits and fossils

Travelling upriver, more and more fine-grained marine sediments appear below river terraces and deltaic sediments. The fine-grained sediments are deepwater marine deposits. At site 28, you can dock the boat and walk up a small gully to view the sediments. In wet weather, the silty clay has very little strength and cannot bear much weight without yielding, but these silty clay slopes are extremely hard in dry weather. Marine shells abound in the clay slopes and the streambed at this site. The most common variety is *Macoma brota*, smaller ones are *Macoma calcarea*, and the crinkly shells are *Clinocardium ciliatum*. The shells have been radiocarbon dated, and give an age of 8270 years before present (reference GSC-6399).

Stop 29: Silt banks

Near the big bend in the river, you will notice that almost the entire river bank is formed of steep walls of silt, with only a thin capping of sand. Steep, triangular facets characterize the bluffs where the river has cut through the coherent marine silt (Fig. 81).

***Figure 81.** Steep cliffs have developed where the river has cut through postglacial marine silt and clay. Photograph by L.A. Dredge. GSC 2000-012CCC*

Figure 82.

Aerial view west of the Coppermine River. Small streams have incised easily eroded silt deposits, exposing them in bluffs. Dark-toned surfaces have a covering of sand. The sand has been removed extensively from some areas by numerous active-layer detachment slides, leaving the bare, light-toned silt exposed. Photograph by L.A. Dredge. GSC 2000-012DDD

Stop 30: Side trip to active-layer detachment slides

Up the side valleys, where slopes are less steep, active-layer detachment slides are common. This form of slope failure occurs where water drains through thawed wet sand, but cannot penetrate into the underlying frozen silt, so that a glide plane, or slippage surface, develops. As a result, masses of sand detach from the underlying sediment and slide down the slope. The top of an active-layer detachment slide has a shallow arcuate backwall. A tongue of rumpled turf and sand protrudes downslope. So many detachment slides have occurred near stop 30 that much of the sand cover has been eroded away, exposing bare silt deposits at the surface (Fig. 82).

Boats can be landed at the foot of the rapids, either at the base of the big gullies (Fig. 83; see *Part IV, Stop 25), or near the bars at the bend on the east side of the river. From there, you can walk the final 3 km to Bloody Fall. On the east side of the river, you will cross marine silt capped with sand, whereas on the west side, you will pass thick deltaic sand deposits.*

Along the beach

The processes acting along the modern beach have already been described in the section on coastal processes. This section summarizes a few points to note as you walk along the shore from Kugluktuk to 4-Mile bay. The numbers of the stops described below correspond to those on Figure 84.

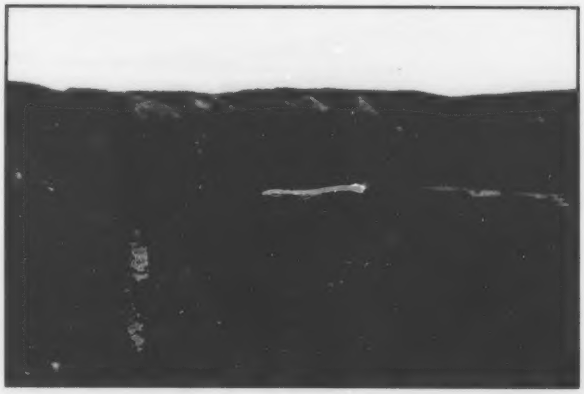


Figure 83. *Sand and gravel, transported and rounded by the river, lie at the foot of the rapids below Bloody Fall. The gullies are seen in the background. Note footprints in foreground for scale. Photograph by L.A. Dredge. GSC 2000-012EEE*

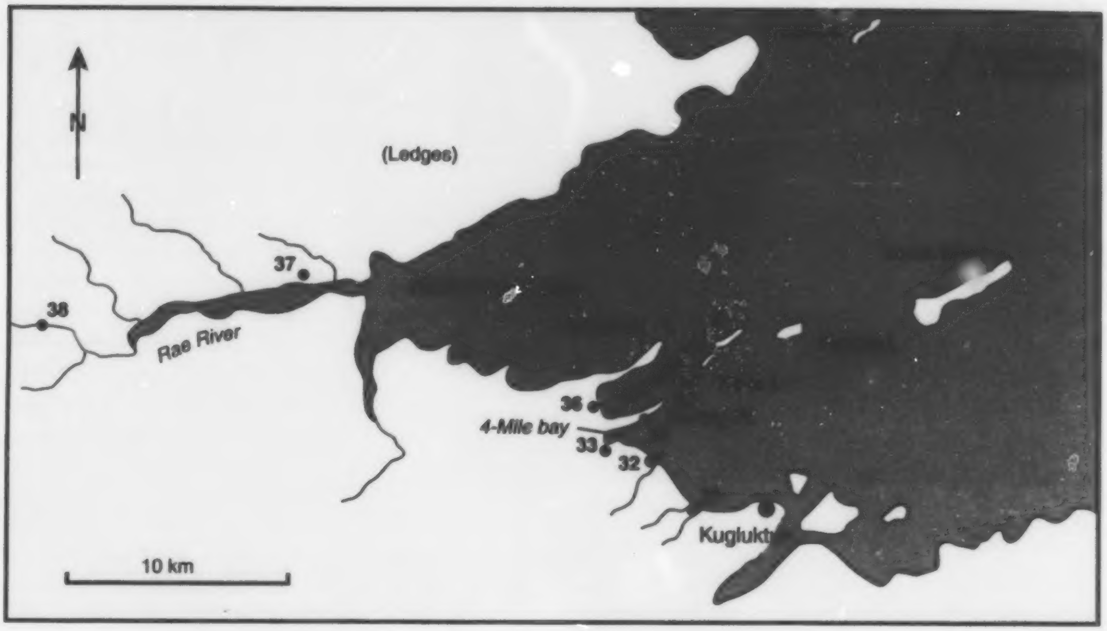


Figure 84. *Locations of stops for the walk along the beach. Numbers correspond to the stop numbers in the text.*

Stop 31: First tower

As you walk to the first small tower, you will see a beach typical of low-energy wave environments, where the beach is prograding, or slowly building out into the sea (Fig. 85). Most of the material is sand, derived from multiple cycles of erosion on local rocks, and reworking of old deltaic or marine sediments. Most sand grains are quartz, feldspar, or pyroxene, but the smaller black grains, usually concentrated in layers near the high water mark, are magnetite.

Although this part of the coast is a shoreline of deposition and is slowly growing seaward, there are small bluffs behind the foreshore, about 2 km farther down the beach, that are indicative of wave erosion.

Stop 32: Second tower

Near the second small tower and behind the present beach are undulating, recently abandoned beach ridges that rise to 2 m above sea level. About 100 m inland from these is a wave-eroded bluff. If the sea stood at

Figure 85. *Beach at the first small tower. Beaches near Kugluktuk are made of well sorted sand. This photo shows the modern beach backed by an older beach, now partly vegetated. Wind activity has created blowouts on the old beach. Photograph by L.A. Dredge. GSC 2000-012FFF*

the base of the bluff about 500 years ago, as is suggested by the regional sea level curve, then the shoreline at this locality has been advancing seaward at a rate of about 20 cm per year.

Stop 33: 4-Mile bay

At 4-Mile bay, sediments carried by creeks flowing into the sea are reworked by waves to form a wide, prograding beach. The rate of deposition far exceeds that of wave erosion. The present beach grades upward and inland into undulating sets of abandoned beach ridges. Those deposited about 1 km inland (10 m elevation) formed about 3500 years ago. This would have been the shoreline when Pre-Dorset people roamed across the region. The rectangular pattern of 'trenches' on these beaches is known as 'ice wedge polygons' (Fig. 86). Massive ice is visible below the mossy vegetation in the depressions. Between the trenches, frozen ground is present at a depth of about 75 cm in summer, but there is little ice.

The beach sand is all underlain by finer sediments deposited in deeper water. Postglacial marine clay, with some sea shells, can be found inland at the base of the creek flowing into the bay.

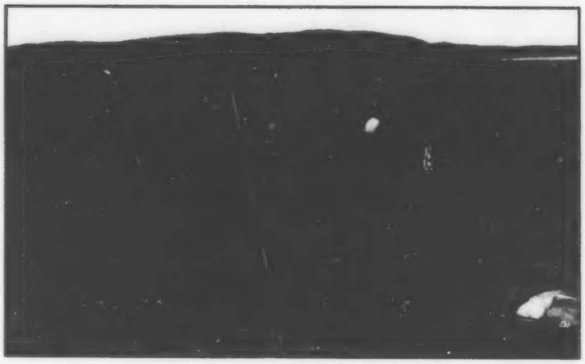


Figure 86. *Series of well vegetated beach ridges above 4-Mile bay. Ice wedges form networks of polygonal depressions that cut across the old beaches. Rock jutting out to Gurling Point creates the cliff in the background. Photograph by L.A. Dredge. GSC 2000-012GGG*

Rae River run

Stop 34: Gurling Point

Gurling Point is named after an Anglican missionary who began work in this area in 1915. The rocks forming the peninsula that extends out to Gurling Point are similar to those at Kugluktuk. The upper rock unit is a gabbro sill, recognized by its dark colour, massive nature, and columnar fracture pattern. Toward the point, the columnar joint pattern forms a series of rock steps from the top of the cliff down to the sea: a giant's staircase.

Below the gabbro are two different types of sedimentary rocks. These appear whiter than those in Kugluktuk, and differ from them in that there is more calcite. Stratification is clearly visible (Fig. 87).

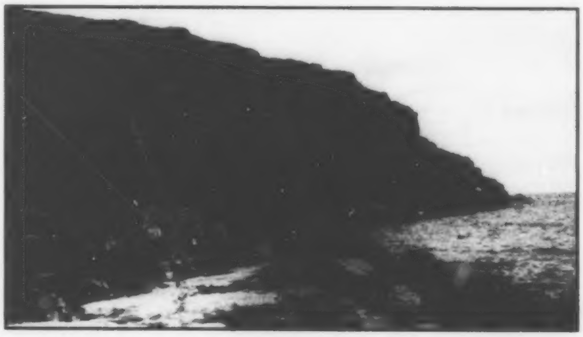


Figure 87. *Sedimentary rocks, mainly evenly bedded argillite and calcareous argillite, form ledges at sea level near Gurling point. Above them are massive columnar structures of gabbro. Cliff is 29 m high. Photograph by L.A. Dredge. GSC 2000-012HHH*

Stop 35: Blaze Island

Blaze Island is an extension of Gurling Point, and is formed of the same rock types. The top of the island affords a scenic view of nearby islets to the west, and the pack ice to the east. Blaze Island is exposed to an environment of higher wave energy than the mainland, and most beaches therefore consist of well rounded cobbles and pebbles (Fig. 88). Limestone pebbles are also more prevalent than on the mainland, a reflection of the proximity of limestone bedrock on the mainland to the west and northwest.

Stop 36: Expeditor Cove

Expeditor Cove is a shallow bay sheltered between two sills that form its eastern and western shores. The cove ends in low grassy wetlands underlain by clay. Small rock knobs near the sills are striated in northerly and westerly directions. On the skyline west of the cove are saw-toothed ridges formed by successive ranks of gabbro sills (Fig. 89).

Proceed past Mackenzie Point and into Richardson Bay.

Stop 37: Rae River

At the mouth of the Rae River are shoals, slightly raised old-delta deposits, and alluvial terraces. In some places, old marine sand and clay are exposed at the surface. Shells collected from the clay near here gave a radiocarbon date of 9400 years before present (9440 ± 120; GSC-39), indicating that they were living in the area shortly after deglaciation.

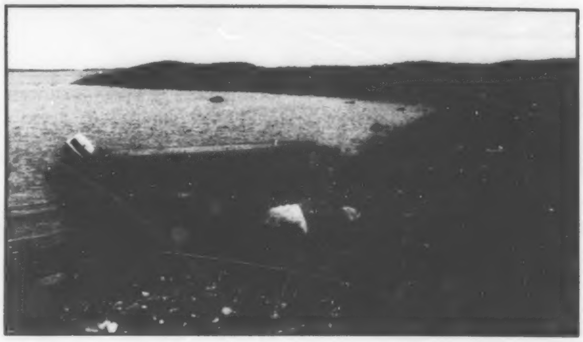


***Figure 88.** A set of raised beaches extends up from sea level on Blaze Island. The beaches in this more exposed environment are composed of gravel and boulders, rounded by wave action. Photograph by L.A. Dredge. GSC 2000-012III*

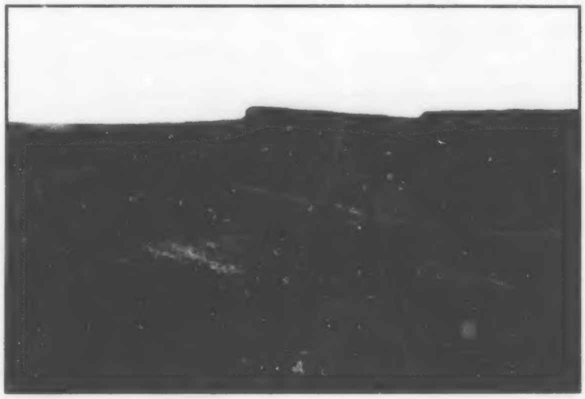


***Figure 89.** Grassy lowlands at Expeditor Cove are underlain by marine clay. Gabbro sills form asymmetric ridges in the distance. Bedrock outcrop in the foreground has been abraded and smoothed by passing glaciers. Photograph by L.A. Dredge. GSC 2000-012JJJ*

Stop 38: Rapids on Rae River

Several interesting features are seen on the north side of Rae River at the rapids. The rapids are created by the river tumbling over a ledge of Proterozoic sedimentary rocks. Fine-grained silt particles in the water give it a turquoise colour. Where the river has swirled boulders around in circles, potholes have been eroded into the bedrock (Fig. 90). Good examples are visible on the lower rock ledge on the north side of the river. On a ledge above the potholes are sandstone units with ripple marks (Fig. 91). The ripples, however, are not produced by the modern river, but rather are lingering remnants of wave activity from approximately 720 million years ago, preserved in the rock.

Also exposed on some of the lower ledges below the falls are the tops of stromatolites, preserved in layers of buff-weathering dolomite. These are the remains of blue-green algae domes that thrived in a Proterozoic tropical lagoon (Fig. 92).

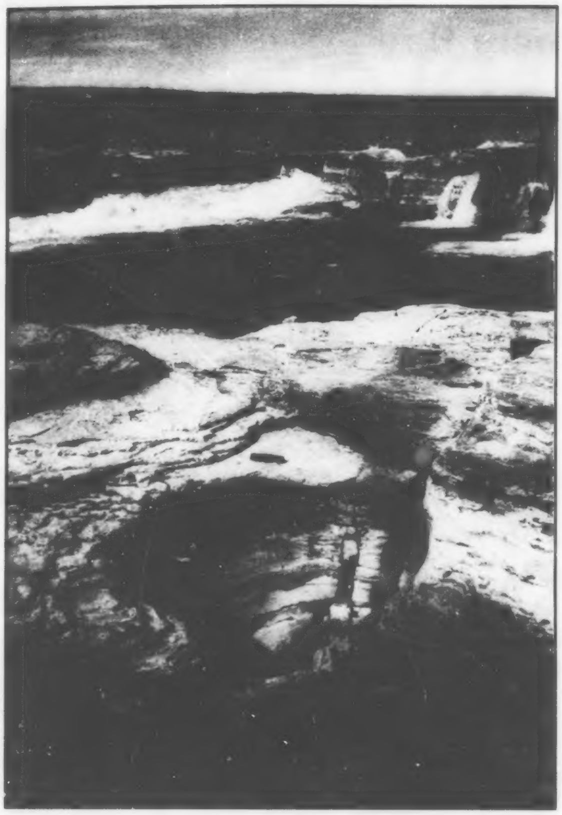


Figure 90. *Scenic rapids have developed along the Rae River where it drops over ledges of sandstone and calcareous argillite. A large pothole in front of the penknife shows how swirling boulders, carried by the river, have eroded a deep depression in the bedrock. Photograph by L.A. Dredge. GSC 2000-012KKK*

Small blebs or tongues of fine black material, stringers of magma extending from the sills far above the river bank, have intruded into the sediments. Around some of these, the adjacent sedimentary rocks have blue-green stains caused by malachite and other copper-bearing minerals. The bright yellow specks are iron- and copper-sulphide minerals. White calcite veins fill some of the fissures in the strata, particularly where the intruding hot magma stringers have altered or 'cooked' the adjacent rock.

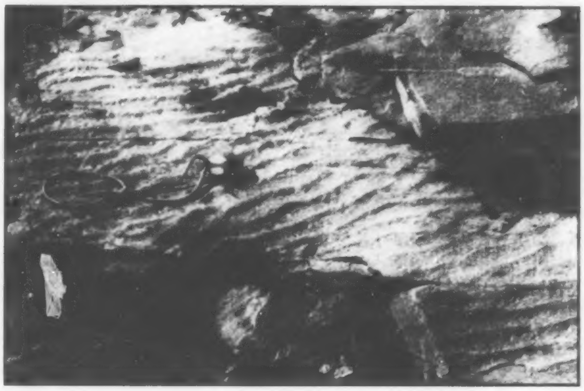


Figure 91. *Ripple marks on sandstone outcrops at the rapids on Rae River record the action of waves on a sandy beach about 720 million years ago. Photograph by L.A. Dredge. GSC 2000-012LLL*

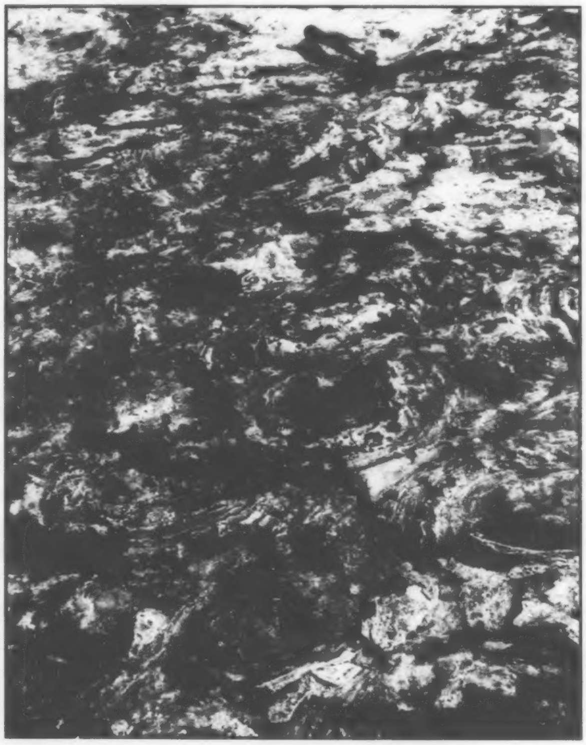


Figure 92. *The circular features forming the bedrock surface are the tops of stromatolites, ancient cabbage-shaped algal colonies that thrived in a tropical sea about 720 million years ago. Light grey, raised rims are made of chert (silica). Intervening buff-coloured parts are dolomite. Hammer at top of photo is 35 cm long. Photograph by L.A. Dredge. GSC 2000-012MMM*

Stop 39: North side of Klengenberg Bay

North of the rapids on Rae River, there are major changes in the landscape. The bedrock is buff-toned limestone and dolomite of Paleozoic age, much younger than the rocks at Kugluktuk. These sedimentary rocks generally form flat, rough-weathering ledges where they are exposed (*see* Fig. 12). Karst solution pits have developed on rock surfaces in limestone when water and carbon dioxide in the atmosphere combined to form weak carbonic acid, dissolving out some of the limestone and leaving a rough upper rock surface. The dissolved material is carried by rainwater to the edges or undersides of the limestone slabs, and is precipitated as miniature stalactites when the water finally evaporates.

On the north side of Klengenberg Bay, some of the bedrock has been split into polygonal networks where ice wedges in the rock fissures have forced up and shattered parts of the rock surface (Fig. 93).

Farther inland, parts of this area that lie above the limit of postglacial marine submergence are covered with glacial till, consisting mainly of ground-up limestone or dolomite. Much of the till surface has been streamlined into drumlins, whose surfaces are covered with mud boils similar to those described for the silty deposits at Kugluktuk.

Figure 93. *Aerial view of rock polygons between Klengenberg Bay and Cape Hearne. These features form along natural fractures in limestone or dolomite bedrock when ice thrusts up the rock along the cracks. Rectangles are 20–40 m across. Photograph by S.A. Wolfe. GSC 2000-012NNN*

Stop 40: Around Cape Hearne

Flights of raised beaches are common landforms near the coast (Fig. 94). These beaches have ridges that are much higher than the subtle undulating forms at Kugluktuk, and are composed of flat limestone shingle (slabs).

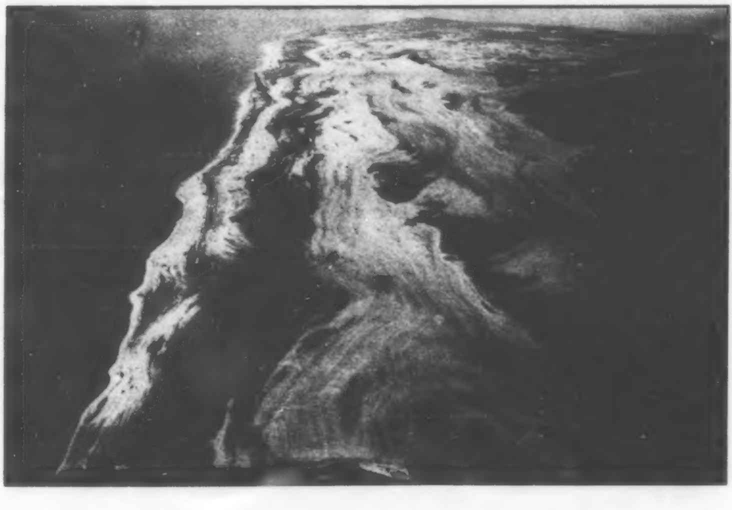


Figure 94.

A set of raised beaches at Cape Hearne ascends inland from the coast. Each beach forms a distinctive berm consisting of flat fragments of broken limestone or dolomite. The beaches end at a cliff face of dolomite bedrock (far right). Photograph by S.A. Wolfe. GSC 2000-012OOO

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GLOSSARY OF TERMS

Active layer. The top layer of ground that thaws each summer.

Active-layer detachment slide. A small, shallow landslide that occurs where saturated soil in the active layer slides downslope, exposing the underlying frozen soil

Aggregate. Construction material that is primarily sand and gravel, or crushed stone.

Alluvium. Sediment that is deposited by a river.

Argillite. A grey, fine-grained rock that forms when clayey sediment is altered by extreme heat and pressure.

Basalt. A fine-grained, black igneous rock formed by rapid cooling of lava.

Bedrock. Solid rock.

Beds. Layers of sediments or sedimentary rock.

Blowout. A shallow circular depression in sand created by wind erosion.

Braided stream. A stream characterized by an intricate network of smaller interlacing channels that repeatedly merge and separate.

Calcite. A mineral consisting of calcium carbonate.

Canadian Shield. The extensive region of stable ancient rocks that forms a large part of the North American continent.

Chalcopyrite. A metallic, brass-yellow copper-iron-sulphide mineral. A principal source of copper.

Clay. Soil particles that are less than 0.002 mm in size.

Columnar jointing. The splitting of a rock (e.g. gabbro) into columns by cracks (joints) produced by contraction as molten rock cools.

Crossbeds. Layers of sand deposited by water or wind that are sloped at various angles.

Cuesta. A hill or ridge with a steep slope on one side and a gentle slope on the other.

Debris fan or alluvial fan. A low, cone-shaped accumulation of sediment that is deposited by a stream at the base of a slope.

Delta. A body of sediment deposited by a river as it empties into an ocean or lake.

Discharge. The quantity of water flowing in a river, measured in cubic metres per second.

Distributary channels. Small river channels separating islands in a delta.

Dolomite. A mineral or a sedimentary rock composed of calcium-magnesium-carbonate.

Drumlin. A long, streamlined hill made of till and glacial sediments, formed beneath a glacier or ice sheet.

Dune. A mound of sand produced by wind or water.

Eolian. Pertaining to wind.

Erratics. Boulders and rocks carried by glacier ice from their place of origin and deposited in an area with a different bedrock type.

Escarpment. A long, continuous cliff.

Esker. A winding ridge of sand or gravel deposited by a steam flowing beneath an ice sheet, and left behind as the ice melted away.

Facet. A planar surface produced by erosion.

Flowslide. A landslide of waterlogged material. In a thaw flowslide, the water comes from melted ice in the soil.

Foreset beds. Inclined layers of sand and silt deposited at the edge of a delta.

Frost heave. The upward or outward movement of the ground surface (or objects in the ground) caused by the formation of ice in the soil or in cracks in bedrock.

Frost jacking. Progressive uplift of objects or rock fragments due to repeated cycles of frost heave.

Frost-shattered rock. Bedrock that has been heaved up and broken due to the expansion of water as it freezes.

Gabbro. A dark, coarse-grained intrusive igneous rock that is the main type of bedrock at Kugluktuk. The main minerals in the rock are feldspar and pyroxene, the latter mineral giving the rock its dark green or black colour.

Glacial lake. A lake that forms because its outlet is blocked by a glacier or ice sheet.

Glacier. A large mass of ice formed by the crystallization of snow, which moves slowly outward from its source area under the stress of its own weight. During the last ice age, coalesced glaciers formed an ice sheet that covered much of Canada.

Gneiss. A common coarse-grained metamorphic rock that is partly banded due to alignment of minerals. Gneiss is commonly derived from granite.

Granite. A light-coloured, coarse-grained igneous rock consisting mainly of quartz, feldspar, and hornblende.

Greenhouse gas. A gas that causes the atmosphere to heat up like a greenhouse. Carbon dioxide, water vapour, and ozone are the main greenhouse gases. Greenhouse gases allow shortwave solar radiation coming into the atmosphere to pass through, but trap outgoing longwave terrestrial radiation, causing the air to heat up.

Ground ice. Ice found below the surface of the ground, especially in lenses, wedges, or irregular masses.

Ground-ice aggradation. Increasing formation of ice in the ground, causing soils and rocks to heave up.

Ground ice degradation. The melting of ice in the ground, causing materials to subside.

Ice lens. A predominantly horizontal, lens-shaped body of ground ice. Ice lenses commonly form in silty soils.

Ice lobe. A tongue-shaped extension of the outer part of a continental glacier, usually flowing in a lowland area.

Ice sheet. A glacier of continental proportions, which may have several coalescing centres of outflow.

Ice wedge. A large, wedge-shaped mass of ground ice, produced in permafrost terrain, that occurs as a vertical sheet or vein tapering downward. Ice wedges extend several metres down into the soil.

Ice-wedge polygon. A polygonal ground-surface pattern produced by networks of ice wedges. The polygonal surface pattern is conspicuous because the tops of the ice wedges thaw in summer, producing sets of shallow trenches.

Joint. A fracture in bedrock that is created during formation of the rock.

Karst. Irregular, pitted landforms, both large and small, that are produced when water dissolves limestone.

Laurentide Ice Sheet. The large ice sheet that covered much of Canada during the last ice age. It reached its maximum extent about 18 000 years ago.

Limestone. A sedimentary rock consisting of calcium carbonate.

Little Ice Age. A period of relatively cold climate lasting from about AD 1500 to AD 1850.

Longitudinal bar. A long, low sand bar aligned parallel to the direction of river flow.

Magma. Molten rock that forms igneous rock upon cooling.

Magnetite. A black, strongly magnetic mineral. It is commonly a constituent of gabbro. Magnetite grains are concentrated in layers on the beach by waves.

Meandering river. A river that curves or loops back and forth in a regular manner.

Mud boils. Bare circular areas of ground, about a metre in diameter and surrounded by vegetated ground, that are produced by churning of the thawed layer of soils by frost action.

Outwash. Sand and gravel deposited by meltwater streams flowing away from an ice sheet or glacier.

Paleozoic. A period of geological time, from 750 to 270 million years ago, in which early life forms developed.

Palsa. A small dome of peat, mud, and lenses of ground ice rising from a wetland.

Peat. Dark, dense accumulation of decayed plant remains, consisting mainly of decomposed moss and reeds.

Permafrost. Ground that remains frozen year round. Ground ice is an important component.

Permeability. The ability of soil or rock to transmit water through pores or cracks.

Precambrian. A geological time period extending from 4.5 billion to 570 million years ago.

Proterozoic. A subdivision of the Precambrian period, extending from 2 billion to 570 million years ago. Most rocks around Kugluktuk formed in this time period.

Pyrite. A shiny yellow mineral consisting of iron sulphide.

Radiocarbon dating. A method of determining the age of organic material (e.g. fossil shells) by determining the amount of radioactive decay of carbon-14.

Raised beach. A beach that now lies above, and inland from, the present shore. Its position results from rebound and emergence of the land after the continental ice sheet melted.

Ripple marks. Small sand ridges, 5 to 10 cm high, formed by waves or river currents.

Roche moutonnée. A rock knob eroded and shaped by a glacier or ice sheet so that it is elongated in the direction of ice flow. The side scoured by the glacier is smooth and gently sloping, whereas the down-ice side is rough and steep. This landform is several metres high.

Rock panel. A large block of bedrock that has been heaved up by frost action.

Sand. Soil particles that are 0.063 to 2 mm in size.

Sandstone. A rock composed of layers of sand that have been cemented together

Sedimentary rock. Rock formed of layers of sediment.

Segregated ice. Pure ice that has formed by the migration of water in a soil, making ice lenses, ice wedges, or irregular ice masses.

Sill. A thick layer of igneous rock which, in its molten state, has intruded into, or was squeezed into, sedimentary rock and is sloped the same way as the beds in the sedimentary rock. Sills at Kugluktuk are made of gabbro.

Silt. Soil particles that are 0.002 to 0.063 mm in size.

Solifluction. Slow downslope movement of a saturated soil, commonly due to the thawing of ground ice.

Striations. Scratches on bedrock created when stones, embedded in the bottom of a glacier, are dragged across bedrock. The striations are parallel to the direction of ice flow.

Stromatolites. Cabbage-shaped fossils formed of alternating layers of calcium carbonate and mud (silica or chert). They are the traces of algal mats that once lived in tropical lagoons.

Terrace. A long, flat surface formed by river or wave erosion or deposition.

Thaw flowslide. A landslide that occurs when ground ice melts, creating unstable conditions along a river bank. The bank disintegrates into a soupy mass of water and soil that flows downslope, leaving a steep arcuate backwall and lot of lumpy material at the base. Flowslides are said to be retrogressive when they start at the river bank and then propagate back into the bluff in a matter of minutes.

Thermal conductivity. The ability of a material to transmit heat.

Thermokarst. A landform or process in which troughs and depressions form as a result of thawing of ice-rich soils.

Till. An unsorted mixture of ground-up rock fragments carried and deposited by a glacier. Materials range from clay size to boulders.

Topples. Huge masses of rock that have fallen off a cliff as a result of being shoved out beyond the cliff face.

Topset beds. Horizontal layers of sand deposited at the top of a delta, and covering foreset beds.

Treeline. The northernmost limit of forests or woodlands.

Tundra. A vegetation zone of lichen, mosses, arctic plants, and small woody shrubs.

Volcanic rocks. Rocks that formed by the extrusion of lava onto the Earth's surface.

Whaleback. A large, smooth, glacially sculptured bedrock knob that is shaped like the back of a whale.

REFERENCES

Baragar, W.R. and Donaldson, J.A.
1973: Coppermine and Dismal Lakes map-areas; Geological Survey of Canada, Paper 71-39, 20 p. (includes map 1337A, scale 1:250 000).

Campbell, F.
1983: Stratigraphy of the Rae Group, Coronation Gulf; *in* Current Research, Part A; Geological Survey of Canada, Paper 83-1A, p. 43–52.

Dyke, A.S. and Prest, V.K.
1987: Late Wisconsinan and Holocene history of the Laurentide Ice Sheet; Géographie physique et Quaternaire, v. 41, p. 237–263.

Edlund, S.A.
1986: Common Arctic wildflowers of the Northwest Territories; Department of Indian Affairs and Northern Development, miscellaneous publication.

Environment Canada
1982: Canadian climate normals, 1951–1980: Volumes SI-1 and SI-2; Environment Canada, Ottawa, Ontario.

Heginbottom, A., Dubreuil, M-A, and Harker, P.
1995: Canada – permafrost; Natural Resources Canada, National Atlas of Canada, Map MCR 4177, scale 1:7 500 000.

Jenness, D.
1928: The people of the twilight; University of Chicago Press, Chicago, Illinois, 251 p. (reprinted 1975).

Kerr, D.E., Dredge, L.A., and Ward, B.C.

1997: Surficial geology, Coppermine (east half); Geological Survey of Canada, Map 1910A, scale 1:125 000.

Lachenbruch, A.H.

1962: Mechanics of thermal contraction cracks and ice wedge polygons; Geological Society of America, Special Paper 70, 69 p.

Markham, W.E.

1981: Ice atlas – Canadian Arctic waterways; Environment Canada, Ottawa, Ontario.

McGhee, R.

1970: Excavations at Bloody Falls, NWT, Canada; Arctic Anthropology, v. 6, p. 53–73.

1990: Canadian Arctic prehistory; Canadian Museum of Civilization, 128 p.

1996: Ancient people of the Arctic; University of British Columbia Press, Vancouver, British Columbia, 244 p.

Morrison, D.

1983: Thule culture in western Coronation Gulf; Archeological Survey of Canada, Mercury Series, Paper 116, National Museums of Canada, Ottawa, 346 p.

Nichols, H.

1975: Palynological and paleoclimatic study of the late Quaternary displacement of the Boreal Forest – tundra ecotone; Institute of Arctic and Alpine Research, Occasional Paper 15, p. 14–32.

St-Onge, D.A.

1980: Glacial Lake Coppermine, north-central District of Mackenzie; Canadian Journal of Earth Sciences, v. 17, p. 1310–1315.

1987: Quaternary geology and geomorphology of the lower Coppermine River valley, District of Mackenzie, NWT; 12th International Quaternary Association (INQUA) Congress, Field Excursion A-22 Guidebook, 32 p.

1988: Surficial geology, Coppermine River; Geological Survey of Canada, Map 1645A, scale 1:250 000.

Wolfe, S.A.

1998: Living with frozen ground: a field guide to permafrost in Yellowknife; Geological Survey of Canada, Miscellaneous Report 64, 71 p.

2000: Permafrost research and monitoring stations, northern west Kitikmeot; Geological Survey of Canada, Open File 3438, 82 p.